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EPA Coal Cleaning Program

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Springfield, VA

Prepared for

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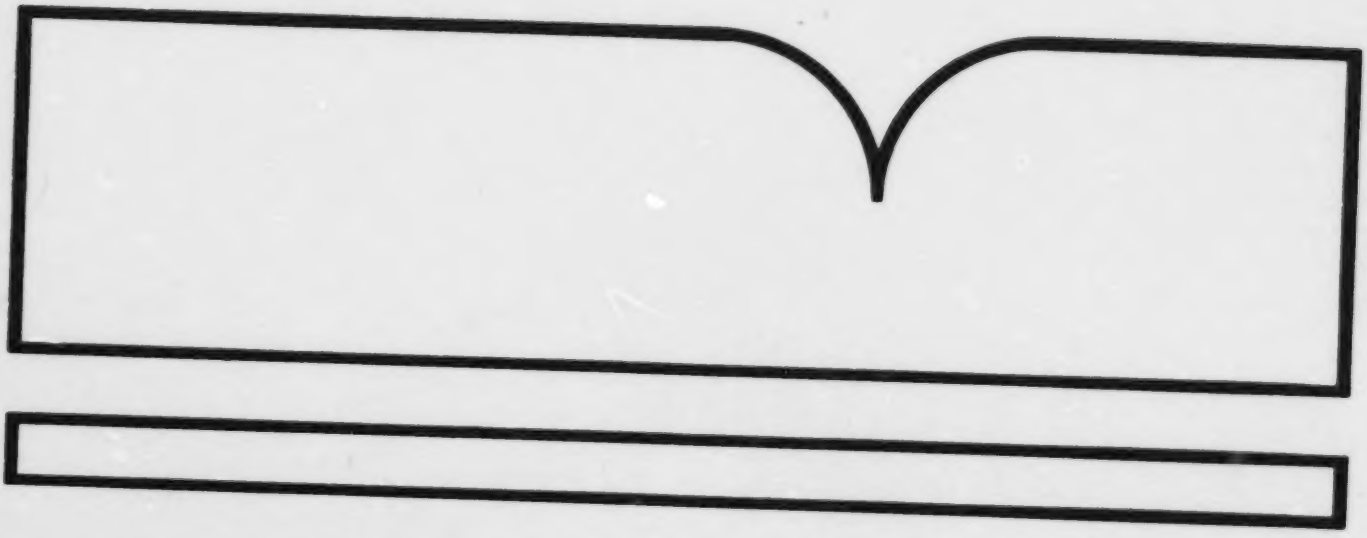

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16. ABSTRACT The report describes work during Fiscal Year 1979 by 12 organizations, both public and private, under EPA's Coal Cleaning Program, a program that explores the possibilities for wider use of coal as an environmentally acceptable energy source. Many aspects of coal were studied, including the use of low sulfur coal, removal of coal sulfur by coal cleaning, and measurement of emissions from the cleaning processes. Seventeen projects were active in three major research categories: environmental assessment, technology assessment and development, and pollution control technology. Several projects were aimed at achieving a better knowledge of the characteristics of estimated coal resources. One approach was to develop and understanding of the effects of geologic formation processes on the properties of the resulting coal--especially sulfur and ash content. Another was to develop empirical data bases from multiple source sampling programs, past and present, to help identify constituents of coal deposits and relate them to environmental and economic concerns. Other studies evaluated certain coal cleaning techniques, equipment, and systems to assess possibilities for their improvement. Alternative strategies were explored for compliance with SO2 emission rules for coal combustion, as were assessment and control of pollution from coal cleaning.

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Coal	Mathematical Models	Stationary Sources	08G, 21D 12A
Combustion	Sampling	Coal Cleaning	21B
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EPA COAL CLEANING PROGRAM: FY 1979 PROGRESS REPORT

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ABSTRACT

This report describes work performed during Fiscal Year (FY) 1979 by a dozen organizations, both public and private, under the U.S. Environmental Protection Agency (EPA) Coal Cleaning Program. This program explores the possibilities for wider use of coal as an environmentally acceptable energy source. Many aspects of coal were studied during 1979, including the use of low sulfur coal, removal of coal sulfur by coal cleaning, and measurement of emissions from the cleaning processes themselves. Seventeen projects were active within three major research categories: environmental assessment, technology assessment and development, and pollution control technology.

Several projects were directed at achieving a better knowledge of the characteristics of estimated coal resources. One approach was to develop an understanding of the effects of geologic formation processes on the properties of the resulting coal--especially sulfur and ash content. Another approach was to develop empirical data bases from multiple source sampling programs, past and present, to help identify constituents of coal deposits and relate them to environmental and economic concerns.

Other studies evaluated certain coal cleaning techniques, equipment, and systems to assess possibilities for their improvement. Alternative strategies for compliance with sulfur dioxide (SO_2) emission rules for coal combustion were explored, as were assessment and control of pollution from coal cleaning processes.

This report was submitted in fulfillment of Contract No. 68-02-3136 by Versar Inc. under the sponsorship of the U.S. Environmental Protection Agency. The report covers the period from October 1, 1978, through September 30, 1979, and work was completed as of June 30, 1980.

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LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

ASTM	— American Society for Testing and Materials
BMP	— Best Management Practices
BSER	— Best System of Emission Reduction
CAA	— Clean Air Act
CCC	— Chemical Coal Cleaning
CEPS	— Coal Environmental Profile System
CPSM4	— Coal Processing Simulation Model
CWA	— Clean Water Act
DOE	— Department of Energy
DSC	— Differential Scanning Calorimetry
EPA	— U.S. Environmental Protection Agency
EPRI	— Electric Power Research Institute
ERDP	— Environmental Research and Development Plan
ESECA	— Energy Supply and Environmental Coordination Act
ESP	— Electrostatic Precipitator
FGD	— Flue Gas Desulfurization
FY 79	— Fiscal Year 1979
HTT	— Hydrothermal Treatment
ISGS	— Illinois State Geological Survey
LASL	— Los Alamos Scientific Laboratory
NPDES	— National Pollutant Discharge Elimination System
NSPS	— New Source Performance Standards
OAQPS	— Office of Air Quality Planning and Standards
OSM	— Office of Surface Mining
OSW	— Office of Solid Waste
PCC	— Physical Coal Cleaning
PEDCo	— PEDCo Environmental, Inc.

LIST OF ABBREVIATIONS AND SYMBOLS
(continued)

ABBREVIATIONS

Penelec	— Pennsylvania Electric Company
PIFUA	— Powerplant and Industrial Fuel Use Act
PURPA	— Public Utilities Regulatory Policies Act
RCRA	— Resource Conservation and Recovery Act
ROM	— Run-of-Mine (coal)
RPAM	— Resource Process Assessment Model
RTU	— Reactor Test Unit
SMCRA	— Surface Mining Control and Reclamation Act
SO_2	— Sulfur Dioxide
STER	— Source Test and Evaluation Report
TEU	— Tail-end Elemental Sulfur Extraction Unit
TRW	— TRW Space Systems Group
TVA	— Tennessee Valley Authority
USGS	— U.S. Geological Survey

CONVERSION/IDENTIFIER TABLE

centimeter (cm) = 0.394 inches (in.)
d = day
degrees centigrade (°C) = 5/9 [degrees fahrenheit (°F) - 32]
F = float fraction
gal/min = gallons per minute
gr = grain
h = hour
J/g = kJ/kg = 0.430 Btu/lb
kilogram (kg) = 2.20 pounds (lb)
kilojoule (kJ) = 0.948 British thermal units (Btu)
liter (ℓ) = 0.264 gallon
M = mesh
meter (m) = 3.28 feet (ft)
metric ton (tdg) = 1.102 tons
microgram (μg) = 1,000 nanograms (ng)
micron (μm) = 39.4×10^{-6} in.
milligram per liter (mg/ℓ) = 0.44 gr/ft^3
520 ng SO_2/J = 1.20 lb $SO_2/10^6$ Btu
S = sink fraction
S.G. = specific gravity
ton/d = ton per day
ton/h = ton per hour
ton/y = ton per year

Fractions and Multiples

10^{-3} milli m	10^{3} kilo k
10^{-6} micro μ	10^{6} mega M
10^{-9} nano n	10^{9} giga G
10^{-12} pico p	10^{12} tera T

MESH SIZES (U.S. Standard unless noted)

Inches	Millimeters	Sieve No.
2.00	50.8	2 in.
1.25	31.8	1-1/4 in.
0.75	19.1	3/4 in.
0.375	9.53	3/8 in.
0.250	6.35	No. 3 (3 M)*
0.125	3.18	No. 6 (6 M)*
0.094	2.38	No. 8 (8 M)
0.079	2.00	No. 10 (10 M) - Tyler No. 9 (9 M)
0.047	1.19	No. 16 (16 M)
0.039	1.00	No. 18 (18 M)
0.033	0.84	NO. 20 (20 M)
0.023	0.59	No. 30 (30 M) - Tyler No. 28 (28 M)
0.0117	0.297	No. 50 (50 M)
0.0083	0.210	No. 70 (70 M) - Tyler No. 65 (65 M)
0.0070	0.177	No. 80 (80 M)
0.0059	0.149	No. 100 (100 M)
0.0029	0.074	No. 200 (200 M)
0.00	0.00	0

* Closest Corresponding Sieve No.

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EXECUTIVE SUMMARY

Significant progress has been made in coal research under the U.S. Environmental Protection Agency Energy and Environment Program. Seventeen projects were active during FY 1979 that covered a wide range of subjects relating to coal properties, preparation techniques, and the environmental implications of coal preparation.

Several projects focused on characterization of coal resources relative to mineral content, trace elements, and geological indicators of coal properties. The U.S. Geological Survey and the Illinois Geological Survey analyzed and interpreted data on thousands of coal samples with the aim of developing predictive techniques for best use of coal from particular areas. Research Triangle Institute, Battelle Columbus Laboratories, Versar Inc., and Teknekron Research, Inc. have worked to develop data bases containing specific coal resource parameters for use in determining coal availability with regard to emissions regulations and environmental and economic impacts. An in-depth program of sampling and analysis is being conducted to develop a solid body of information on multimedia emissions from coal preparation plants.

Promising coal cleaning techniques have been developed, improved, and compared technically and economically. Battelle has continued to improve its Hydrothermal process for coal cleaning and has worked to evaluate its potential for sulfur removal. Pennsylvania Electric Company (Penelec) continued development of the Homer City Demonstration Coal Cleaning Plant and The Department of Energy (DOE) conducted dense-medium cyclone tests at its Bruceton, Pennsylvania, facility. General Electric continued an evaluation of the desulfurization potential of microwave treatment of coal.

Versar compiled data on commercial coal preparation equipment and assessed the applicability of physical coal cleaning, chemical coal cleaning, and

use of low sulfur coal for compliance with SO_2 emission regulations. Versar has also obtained commercial coal preparation performance data on flotation, dense media cyclones, and hydrocyclones. The Tennessee Valley Authority (TVA) evaluated seven coal cleaning processes and is beginning to develop a computer model to determine optimum approaches for sulfur removal using combinations of physical coal cleaning and limestone scrubbing. PEDCo investigated the benefits of burning cleaned coal versus run-of-mine coal for utility boilers.

Control of pollution from the coal cleaning process itself was the subject of four additional studies. TVA worked to characterize the fine refuse wastes along with wastes from coal-fired power plants. That project also included testing leachate from solid wastes. Los Alamos Scientific Laboratory (LASL) conducted additional leachate tests and studied control methods for trace elements from coal preparation coarse refuse waste piles. TRW investigated corrosion problems in its (Meyers) Reactor Test Unit and discovered a possible method for reprocessing gob piles for recovery of a portion of the coal refuse for fuel. Battelle continued work on control of pollution from preparation plant blackwater.

The EPA program approach encourages the exchange of ideas and information directed toward common goals and offers all program participants, coal users, and the coal industry the opportunity to benefit from the successes of each project. In this way the coal industry and the United States as a whole can achieve maximum progress toward the twin goals of environmental protection and increased energy obtained from coal.

SECTION 1

INTRODUCTION

United States mineable coal resources are estimated at 1.5×10^{12} kkg,[1] enough to supply the United States with electric power for 800 years at 1976 consumption rates.[2] This large resource seems to offer the answer to a variety of U.S. energy needs. In addition, coal is a versatile fuel which can be tailored to many specific uses by appropriate preparation and treatment. The field of coal preparation benefits has not been fully explored and, to that end, EPA is coordinating studies in a Coal Cleaning Program in conjunction with the U.S. Departments of Energy and the Interior. This program aims to evaluate the multiple possibilities of coal preparation and to assist in development of technologies for coal beneficiation and concurrent pollution control. During 1979, EPA sponsored work on 17 projects related to coal preparation, which were carried out by a dozen organizations.

This report describes the activities and accomplishments of the Coal Cleaning Program participants during fiscal year 1979 (October 1978 through September 1979). Individual summaries were requested of each project leader and these are presented in Section 4 in the order listed in Table 1-1.

The EPA Coal Cleaning Projects often have multiple and interconnecting aspects, but they may be loosely grouped into three categories:

- Environmental Assessment - Five projects focus on development of data bases in the area of environmentally sensitive coal resource characteristics and coal preparation facility emissions.
- Technology Assessment and Development - Another area of concern, presently critical to electric utilities, is coal's potential for sulfur oxide emissions during combustion. Eight studies

TABLE 1-1. ACTIVE EPA COAL CLEANING PROJECTS

Project Title	Annual Report Section	Directing Organization	Performing Organization	Objectives in 1979
Environmental Assessment:				
Coal Quality	4.1.1	EPA	U.S. Geological Survey	Typify the chemical, mineralogical, and physical properties of U.S. coal resources.
Geology of Contaminants in Coal	4.1.2	EPA	U.S. Geological Survey	Determine the geologic controls on the variation of mineral matter in coal.
Mineral Matter and Trace Elements in Coal (Grant R806654)	4.1.3	EPA	Illinois Geological Survey	Characterize coal with respect to mineral matter and chemical elements.
Coal Environmental Profile System	4.1.4	EPA	Research Triangle Institute	Provide a data base for environmental characterization of U.S. coals.
Environmental Assessment Study	4.1.5	EPA	Battelle Columbus Laboratories/ Versar Inc./ Teknekron, Inc.	Provide emissions data on coal preparation facilities, perform environmental and economic trade-off studies, and identify research needs in pollution control technology and environmental effects.

(continued)

TABLE 1-1. (continued)

Project Title	Annual Report Section	Directing Organization	Performing Organization	Objectives in 1979
Technology Assessment and Development:				
Battelle Hydrothermal Process	4.2.1	EPA	Battelle Columbus Laboratories	Improve economic viability of the hydrothermal process and determine its potential for coal desulfurization.
Homer City Coal Cleaning Plant	4.2.2	EPA/DOE/ EPRI/Penelec	Pennsylvania Electric Company	Provide test planning and support for the Homer City Coal Cleaning Demonstration Project.
Dense-Medium Cyclone Project	4.2.3	DOE/Penelec	U.S. Department of Energy	Detail and optimize performance of dense-medium cyclones at lower than normal specific gravities of separation.
Coal Cleaning Technology Assessment	4.2.4	EPA	Versar Inc.	Assess FGC applicability as an SO_2 pollution control technique, evaluate performance of commercial coal cleaning equipment, and characterize coal sulfur variability.
Evaluation of Physical and Chemical Coal Cleaning	4.2.5	EPA	Tennessee Valley Authority	Evaluate seven coal cleaning processes for sulfur removal and economic viability.

(continued)

TABLE 1-1. (continued)

Project Title	Annual Report Section	Directing Organization	Performing Organization	Objectives in 1979
Technology Assessment and Development (continued):				
Physical Coal Cleaning Economic Model	4.2.6	EPA	Tennessee Valley Authority	Develop a computer program to determine the most economical approach for sulfur removal with FCC and limestone scrubbing.
Coal Cleaning Costs and Benefits	4.2.7	EPA	PEDCo Environmental Inc.	Identify and quantify the benefits of cleaned coal versus ROM coal for utility steam generation.
Microwave Desulfurization	4.2.8	EPA	General Electric Company	Investigate microwave magnetization of pyrite as a desulfurization technique.

(continued)

TABLE 1-1. (continued)

Project Title	Annual Report Section	Directing Organization	Performing Organization	Objectives in 1979
Pollution Control Technology:				
Environmental Studies on Coal Cleaning Processes	4.3.1	EPA	Tennessee Valley Authority	Characterize wastes from coarse coal cleaning plant and coal-fired power plant and perform leachate testing on solid wastes.
Preservation of Reactor Test Unit & Desulfurization of Gob Piles	4.3.2	EPA	TRW Inc.	Investigate corrosion and recommend equipment modifications in equipment for Meyers reactor test unit. Investigate potential of Gravichem process.
Trace Element Characterization and Removal or Recovery from Raw Coal and Coal Preparation Wastes	4.3.3	EPA/DOE	Los Alamos Scientific Laboratory	Assess the problem of trace element contamination in coal waste drainages and identify controls.
Effluent Control by Oil Agglomeration	4.3.4	EPA	Battelle Columbus Laboratories	Evaluate the potential of oil agglomeration as an effluent control technique for coal cleaning blackwater.

concentrated on development or refinement of techniques for removal of sulfur and other contaminants from coal, and on evaluation of alternative cleaning technologies.

- Pollution Control Technology - Contaminants removed from coal during the preparation process must be handled and disposed of in an environmentally sound manner. Four projects dealt with control of pollution from coal cleaning, in particular, solid wastes.

EPA's coordination of these coal cleaning studies has facilitated exchange and synthesis of ideas among project investigators by making the capabilities and information developed under one project available to other projects within the Coal Cleaning Program.

SECTION 2

DEVELOPMENT DIRECTIONS

THE MARKET FOR COAL CLEANING

The benefits of coal cleaning have not as yet been fully defined, and changing environmental and energy goals continue to impose new demands on coal use. Traditionally, coal preparation has meant sizing and removal of mineral matter for optimum coal combustion. Today the process may include dewatering, removal of sulfur and ash, and blending of coals for uniformity. Advanced boiler design has not eliminated the need for coal cleaning, but rather has demonstrated that coal cleaning provides benefits in improved boiler reliability and lower maintenance and transportation costs.

The preparation process has become increasingly sophisticated as emphasis shifts from removal of gross impurities (e.g., rock) to removal of sulfur and trace elements whose release to the atmosphere is environmentally unacceptable.

The fact that cleaning can reduce the sulfur content of coals has been established, but some of the potential costs, benefits, and liabilities associated with coal cleaning have not been quantified. These include the degree to which coal cleaning will reduce coal sulfur variability, the comparable costs for controlling sulfur variability in coal by flue gas desulfurization (FGD), and the reduction in boiler operating and maintenance cost which may result from coal cleaning. When these analyses have been completed, the market for cleaned coal can be expected to expand. In addition, sulfur removal by coal cleaning may now be credited toward the 90 percent reduction requirements of the New Source Performance Standards (NSPS) for utility boilers. If a similar approach is taken for industrial boiler standards which are to be promulgated in 1981, the demand for cleaned compliance coals may expand.

As energy needs mandate the development of synthetic fuels from coal, improved control of coal properties is desirable because some conversion processes are extremely sensitive to feedstock variations. Not all coal properties are understood in relation to their impact on coal conversion process efficiency. Research to provide more knowledge of the correlation would be useful in determining the optimum specifications for feed coals used in conversion processes. If coal preparation techniques could be used to modify coals to meet these specifications, coal cleaning could provide a valuable impetus to synfuels production.

Some advances in coal cleaning are pointing to other benefits, such as recovery of fuel values by the reprocessing of old coal refuse. Such techniques provide energy from waste and simultaneously reduce land disposal requirements for coal refuse.

RESEARCH AND DEVELOPMENT OBJECTIVES

Coal cleaning projects active during 1979 reflect numerous short- and long-term goals for coal cleaning research and development.

Short-Term Objectives

The following immediate goals are embodied by the research program:

- Characterization of coal sulfur variability and the degree to which coal preparation attenuates this variability.
- Identification of improved coal cleaning techniques that will provide for maximum pyrite removal with minimum coal energy losses.
- Evaluation of the environmental impacts of coal cleaning.
- Development of technology to control trace elements in leachate from coal preparation plant wastes.
- Establishment of costs of alternative strategies for compliance with SO_2 emission standards by coal-fired industrial and utility boilers.

Long-Term Objectives

The following long-term objectives of this program have been defined:

- Characterization of U.S. coals and their mineral and elemental contaminants.
- Development of techniques for the control of newly regulated pollutants and new coal cleaning technologies.

SECTION 3

REGULATIONS AND TECHNOLOGIES

REGULATORY STATUS

The directions of coal production, beneficiation, and use in the U.S. are shaped to a considerable extent by legislative actions designed to protect natural resources and to increase the use of coal as an energy source in preference to oil or natural gas. These concurrent goals can only be achieved through technological developments that will offer maximum energy yield with a minimum of environmental impact.

Control of pollution from the combustion of coal can be achieved by collection of pollutant emissions during or after combustion or by removal of contaminants from the coal before burning. Pollutants from the coal preparation process are of concern also.

Laws which focus on air, water, and solid waste as well as mining operations have generated regulatory controls in these areas, often resulting in overlapping requirements and duplicate rules. The Federal Government is taking steps to consolidate these controls, but many rules are still in the process of development and time is needed to coordinate the perspectives of different regulatory program offices.

Air Quality Regulations

Air pollution control requirements stem from the Clean Air Act (CAA), with primary ambient air standards for protection of human health and secondary standards for protection of the environment.

Under the CAA, the U.S. has delineated air quality control regions to establish standards for upgrading ambient air quality and to aid in state decision-making on emission limits for individual industrial facilities.

Certain pollutants have been designated as requiring control: particulates, ozone, carbon monoxide, hydrocarbons, lead, nitrogen oxides, and sulfur oxides. Hazardous air pollutants currently of concern include asbestos, beryllium, mercury, arsenic, vinyl chloride, and radionuclides. Regulations are scheduled for promulgation in 1981 to specify controls on radionuclides in the environment, and may apply specifically to radiation from coal-fired power plants, among other sources. The radionuclides in question include Radon 222, Uranium 238, and Thorium 323.

Fugitive dust is still being studied, and limits are expected to be set on this pollutant when coal mining and coal preparation new source performance standards are reviewed. Secondary effects of sulfur emissions from coal combustion—sulfuric acid production in the atmosphere—are becoming more serious, with the pH of rain in Canada and the U.S. decreasing steadily and hundreds of lakes becoming so acidic as to be incapable of supporting fish. Some technical solutions must be found to reverse this trend and at the same time to allow continued burning of coal.

New Source Performance Standards for utility boilers published in June 1979 are of consequence to the coal industry. They prohibit particulate emissions from coal-fired boilers in excess of 13 ng/J (0.03 lb/10^6 Btu) and 20 percent opacity. Sulfur dioxide limits for these facilities are 520 ng/J (1.20 lb/10^6 Btu) with a 90 percent reduction in potential combustion concentration of sulfur dioxide. If SO_2 emissions are less than 260 ng/J (0.60 lb/10^6 Btu), a 70 percent reduction in potential combustion concentration is acceptable. Reductions in sulfur prior to combustion can be credited to this requirement in both cases.

These standards will be incorporated into State Implementation Plans (SIPs) which describe the state regulatory framework for control of air pollution. States develop individual facility permits based on these authorities.

Water Quality Regulations

The federal mandate for protecting the waters of the United States stems primarily from the Federal Water Pollution Control Act, commonly referred to as the Clean Water Act (CWA). Federal effluent limits are established for specific industries as guidelines for permitting.

These effluent limitations are applied to individual facilities by the National Pollutant Discharge Elimination System (NPDES) mandated by the CWA. Under this system, permits are required for any point source whose discharges can enter U.S. waters. The permits are issued by EPA or by one of 32 states whose water management programs have been approved by EPA. Amendments added to the CWA in 1977 require reconsideration of effluent standards to allow inclusion of the 129 toxic substances listed by a court-approved Consent Degree of July 7, 1976. Any toxic substances found to be characteristic of discharges from coal preparation plants will be included in effluent limitations standards. These limits will be based on Best Available Control Technology.

EPA also promotes Best Management Practices (BMP) to control toxic or hazardous pollutants from plant site runoff, spillage or leaks, sludge or disposal, and drainage from stored raw materials. Planned BMP practices will be submitted as part of facility NPDES permit applications and will be approved or disapproved by the permitting agency. An EPA guidance document has been published that discusses BMP's in general, but does not focus specifically on coal cleaning plant requirements.

Ground-water quality is protected by the Safe Drinking Water Act. This Act could also apply to coal wastes if they are returned to underground workings--a practice not currently in use.

Protection of ground water and surface water is also of concern to EPA's Office of Solid Waste (OSW). Standards promulgated by that office under the Resource Conservation and Recovery Act of 1976 (RCRA) require careful facility siting and ground-water monitoring to prevent and detect leachate seepage from waste impoundments or landfills. This concern is also reflected in the Department of Interior's Office of Surface Mining (OSM) regulations which require submittal of an engineering plan showing location of waste areas and specific disposal procedures as a prerequisite for an OSM permit to conduct mining operations.

Energy Regulations

Various federal laws mandate the Department of Energy to study coal as an energy source from the standpoint of encouraging its use, funding basic research, estimating future use and environmental results of that use, and developing new technologies to enable coal to be more reliably cleaned.

The Energy Supply and Environmental Coordination Act of 1974 (ESECA) contains directives relating to air pollution in connection with the Federal Energy Agency's encouragement of coal use. Certain of these provisions were incorporated into the CAA, and ESECA itself was superseded by the Federal Energy Administration Act of 1974, as amended in August 14, 1976. This law provided for a National Energy Information System which would facilitate analysis of energy supply and consumption within the U.S. Information required includes data on the sensitivity of energy resources to environmental and technological considerations.

The Department of Energy Act of 1978 required research into coal conversion and improved coal combustion techniques and specified that environmental and safety aspects must be included.

The Public Utilities Regulatory Policies Act of 1978 (PURPA) amends the Surface Mining Control and Reclamation Act (SMCRA) to provide support for university coal research on advanced concepts related to coal conversion and use.

The Powerplant and Industrial Fuel Use Act of 1978 (PIFUA) requires that major fuel-burning installations must burn coal. Exemptions can be obtained for several reasons, one of which is the facility's demonstrated inability to use the coal in an "environmentally sound" manner. The law also mandates a national coal policy study and report from the President to the public in November 1980.

TECHNICAL STATUS

Coal is a heterogeneous substance containing complex organic molecules as well as inorganic molecules and nearly all of the naturally occurring elements. Constituents of particular concern are sulfur and trace elements, including radionuclides, which are released to the atmosphere during combustion of the coal. Other coal characteristics of importance are its ash content and slagging properties and its heating value in relation to all of the above. The Coal Cleaning Program supports research on many of these characteristics and constituents, the most significant of which is sulfur.

> "Sulfur in coal occurs in three forms—organic, sulfate, and pyritic. Organic sulfur, which is an integral part of the coal matrix and which generally cannot be removed by direct physical separation, comprises 30-70% of the total sulfur of most coals. Generally, the organic sulfur-total sulfur ratio is highest for low-sulfur coals and decreases as the total sulfur content increases.
>
> The sulfate is normally an oxidation product which is water soluble and therefore readily removed during coal cleaning. Sulfate sulfur content is usually less than 0.05%.
>
> Pyritic sulfur in the form of mineral pyrite occurs in coal as discrete and sometimes microscopic particles. It is a heavy mineral with a specific gravity of about 5.0 whereas coal has a maximum specific gravity of only 1.8. The pyritic sulfur content of a coal generally can be reduced significantly by size reduction and subsequent specific gravity separation."(3)

Present commercial physical coal cleaning (PCC) separation techniques are based on surface properties and differences in specific gravities. More sophisticated PCC techniques currently being investigated are based on magnetic or electrokinetic properties of coal. All processes include crushing, sizing, cleaning, dewatering, and auxiliary operations like transport, handling, storage, refuse disposal, emissions control, and recovery operations. More than 40 percent of all coal burned in the U.S. is physically cleaned in some way.

Chemical coal cleaning (CCC) techniques are presently being studied at the laboratory and pilot-plant stage. CCC usually involves grinding the coal into small particles and treatment with or without chemical agents at elevated temperatures and pressures. The sulfur in the coal is converted

through chemical reaction to elemental sulfur or to sulfur compounds that can be physically removed from the coal.

A number of new coal cleaning processes, most involving chemical or physical-chemical techniques, are currently being developed to produce coals which will comply with SO_2 emission standards. With accelerated development, some of these emerging technologies could be used commercially as early as 1985.

Another aspect of coal use now emerging is conversion to synthetic fuels. Special preparation of coal could enhance the conversion processes, increase their efficiency and product yields, and decrease system down-time.

Contaminants removed by the cleaning process prior to combustion of the coal must be controlled and disposed in an environmentally sound manner. These wastes include air emissions from thermal dryers and haul roads, aqueous discharges from settling pond overflow or waste pile runoff, and acid leachate from weathered waste piles. Projects within the EPA Coal Cleaning Program are focusing on emissions from coal cleaning processes, particularly solid waste and its attendant air and water pollution problems.

SECTION 4

RESEARCH AND DEVELOPMENT PROGRESS

The EPA Coal Cleaning Program contains three basic elements:

- Assessment of the environmental impacts of coal cleaning.
- Assessment and development of coal cleaning technologies.
- Development of pollution control technology for coal cleaning processes.

Government organizations participating in the program include the Environmental Protection Agency, the Department of Energy, the Department of the Interior, and the Tennessee Valley Authority. The program is directed for EPA by the Industrial Environmental Research Laboratory, Research Triangle Park, North Carolina. Table 1-1 summarizes projects active during FY 1979 and cites the sections of this report in which they are discussed.

ENVIRONMENTAL ASSESSMENT

The goal of this portion of the EPA Coal Cleaning Program is to compile and evaluate data on the physical and geochemical properties of U.S. coals relative to their geologic settings. Data on coal reserves and their characteristics are to be compiled and computerized to provide a basis for decision-making on coal use strategies.

Coal Quality

A program being performed by the U.S. Geological Survey (USGS) addresses characterization of coal quality. The overall objective of this program is to typify the chemical, mineralogical, and physical properties of U.S. coal resources. Long-range goals of the program are to collect and analyze an adequate number of samples from each of the major and minor coal beds of the country and identify trends of these components and physical

properties in each coal bed. Maps showing these compositional trends will be published. These data will be used to identify coal beds, or areas within beds, with compositions which pose environmental problems for various process applications.

The analytical flowchart of the analyses performed on eastern coal is shown in Figure 4-1. The analyses performed on western coal are somewhat different for some elements. During FY 79 a total of 660 samples from the eastern U.S. coals was analyzed. Approximately 500 samples of western coals were also analyzed. The analytical data on each of 617 eastern coal samples collected in FY 78 and statistical summaries of those data were reported by Zubovic and others (1979).[4] The data for 660 coal samples analyzed during FY 79 are now being compiled. Statistical summaries of these data on 19 elements considered to be deleterious to the environment are presented in this report.

In general, averages of FY 79 analytical results agree with those of FY 78 (Table 4-1). Only As, Be, Hg, and Pb were significantly different from one year to the next. Comparison of the FY 79 eastern coal averages with averages for 4,810 samples of U.S. coals showed that eastern coals had higher average contents of most of these elements. Only Cd and Mn were significantly higher in the average U.S. coal than in eastern coals.

Table 4-2 shows the observed range of analytical values, the geometric mean, and the geometric deviation for each element in the 644 bituminous coal samples to be reported for FY 79. Of primary interest in these data is the variability in the concentration of these elements in coal. The maximum/minimum ratios range from 26 for sulfur to 2,250 for cadmium. With an adequate sample density, coal beds or areas within coal beds with abnormally high trace element contents can be identified. Assessments can then be made for the best use of such coals or for needs in cleaning or processing of these coals to meet environmental and technological constraints.

The data in Table 4-3 are geometric means for samples collected in each state for FY 79. Included in this table are 16 samples of anthracitic

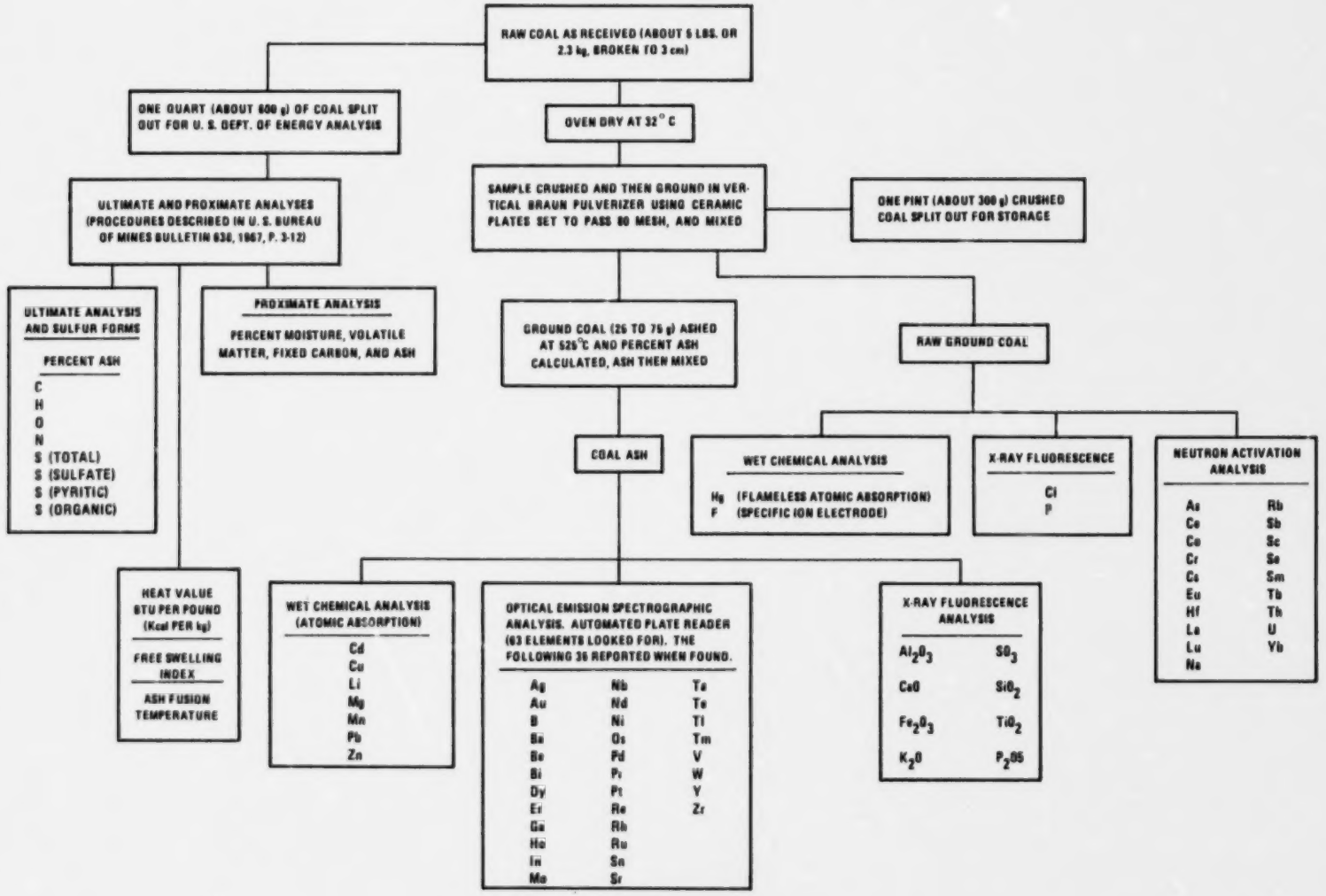

FIGURE 4-1 ANALYSES PERFORMED ON EASTERN COAL SAMPLES

TABLE 4-1. COMPARISON OF THE TRACE ELEMENT CONTENT AND SULFUR OF EASTERN BITUMINOUS COALS WITH AVERAGE U.S. COALS[α]

Elements	U.S. Coals[ϕ] 4810 Samples	Eastern U.S. Bituminous Coals[ψ] 617 Samples (1978)	Eastern U.S. Bituminous Coals[β] 644 Samples (1979)
As	5.1	7.4	8.7
Be	1.4	2.4	1.9
Cd	.14	.08	.08
Co	3.5	5.5	6.2
Cr	9.4	14	14
Cu	12	14	15
F	64	64	67
Hg	.09	.10	.15
Li	8.3	12	15
Mn	25	14	14
Mo	1.8	1.8	1.7
Ni	7.3	12	12
Pb	7.0	5.9	7.3
Sb	.58	.69	.75
Se	1.7	2.9	2.9
U	1.3	1.2	1.5
V	15	17	16
Zn	14	13	14
S %	1.13	1.5	1.45

α All data are parts per million in coal except sulfur which is in percent in coal.
ϕ Zubovic, P., J. R. Hatch, and J. H. Medlin, 1979.
ψ Zubovic et al., 1979.
β Zubovic et al., to be published.

TABLE 4-2. RANGE OF VALUES AND GEOMETRIC MEANS AND DEVIATIONS FOR 19 ELEMENTS IN 644 SAMPLES OF EASTERN BITUMINOUS COALS[α]

Elements	Minimum	Maximum	Geo. Mean	Geo. Deviation
As	1.0	170	8.7	3.79
Be	.22	14	1.9	1.80
Cd	.004	9.0	.08	2.46
Co	.80	90	6.2	1.96
Cr	2.3	84	14	1.92
Cu	2.7	160	15	1.82
F	13	1900	67	2.13
Hg	.01	1.8	.15	2.85
Li	1.0	370	15	2.46
Mn	.96	1400	14	2.90
Mo	.13	16	1.7	2.28
Ni	1.4	130	12	2.00
Pb	1.0	62	7.3	2.14
Sb	.10	7.4	.75	2.25
Se	.60	20	2.9	1.99
U	.10	15	1.5	1.91
V	1.8	120	16	2.05
Zn	1.3	1600	14	2.68
S %	.40	10.4	1.45	2.22

α All data are parts per million in coal except sulfur which is in percent in coal.

TABLE 4-3. COMPARISON OF GEOMETRIC MEANS FOR 19 ELEMENTS IN COAL SAMPLES BY STATES [a]

Source Coal Rank # of Samples	All Coals Bit. (644)	Pennsylvania Bit. (132)	Ohio Bit. (101)	Maryland Bit. (25)	W. Virginia Bit. (254)	Virginia Bit. (83)	Indiana Bit. (49)	Mass. & Rhode Island Anthracite (16)
As	8.7	12	13	15	5.9	7.9	12	7.0
Be	1.9	2.2	2.0	1.6	1.8	1.6	2.7	1.0
Cd	.08	.08	.10	.11	.06	.06	.20	.09
Co	6.2	6.6	4.8	9.2	6.2	5.9	8.2	3.3
Cr	14	17	18	28	12	12	12	13
Cu	15	14	12	18	15	18	16	5.9
F	67	44	87	74	67	85	59	140
Hg	.15	.21	.18	.43	.11	.13	.10	.04
Li	15	20	22	22	12	13	8.3	15
Mn	14	13	28	11	10	19	14	280
Mo	1.7	2.7	2.6	2.4	1.2	1.1	2.1	1.0
Ni	12	16	11	14	11	8.5	25	9.1
Pb	7.3	10	6.8	9.6	6.1	5.2	14	7.1
Sb	.75	.92	.56	.69	.68	.73	1.3	.96
Se	2.9	3.6	3.5	3.5	2.7	2.3	2.6	------
U	1.5	1.2	1.3	1.7	1.5	1.8	1.6	.56
V	16	20	18	21	14	13	14	15
Zn	14	17	24	31	9.0	9.8	36	24
S	1.45	1.73	3.55	1.99	.97	.88	3.55	.76

[a] All data are parts per million in coal except sulfur which is in percent.

coals from Massachusetts and Rhode Island which are not included in the calculated averages of coals analyzed during FY 79. These anthracitic coals had relatively low average values for most of the elements compared to those found for the bituminous coals; only F, Mn, and Zn were found to be comparatively high in the anthracitic coals. Virginia and West Virginia bituminous coals had the largest number of elements with low average values, whereas Maryland and Indiana bituminous coals had the largest number of elements with high average values. Detailed analytical data on individual samples will be available from Zubovic and others, 1980.[5]

USGS expects to complete this study in about three years. In each of these years about 600-650 samples of eastern U.S. coals will be analyzed according to the scheme in Figure 4-1. A comparable number of western coals will also be investigated. In addition to the analyses shown in Figure 4-1, petrographic studies of selected samples from most of the major coal beds will be made. Mineralogical studies of low temperature ash of some of the samples on which chemical analyses were performed are in progress.

Geology of Contaminants in Coal

A second USGS coal cleaning project in the EPA Coal Cleaning Program is the correlation of coal geology with coal contaminants. The coal project was established to determine the geologic controls in the variation of mineral matter in coal because of the use of coal requires new information on the distribution of chemical, mineralogical, and physical parameters of coal beds. Such parameters are known to affect the efficiency of various fuel usage technologies and, in some cases, to produce deleterious environmental effects. Coal resource predictive models can achieve several goals:

- Minimize exploration and development costs.
- Maximize the use of existing data.
- Aid in the determination of the best technical uses, possible environmental consequences, and conversion characteristics of coal.

The project consists of four phases. The first phase focused on the geologic controls on mineral matter variation of the Homer City, Pennsylvania, dedicated reserves of the Upper Freeport coal bed. The second phase is designed to relate geologic factors identified in phase one to coal preparation characteristics. The third phase will be the investigation of geologic controls on the regional variation of mineral matter in the Upper Freeport coal bed. Phase four will test models developed for the Upper Freeport coal bed on at least three other major producing coal beds of the United States.

During FY 79, all work related to phase one was completed, and a final report is in preparation. All laboratory work on phase two was completed, and data synthesis was initiated. The field work for phase three was completed, and laboratory work is nearing completion.

Phase one field investigations included detailed descriptions and sampling of the coal (21 complete channel and 75 bench-channel samples) and associated rocks. Laboratory analyses included:

- Determination of the concentrations of 70 elements.
- Ultimate, proximate, and sulfur forms.
- Pyrite morphological analysis.
- Low temperature ash X-ray mineralogy.
- Scanning electron microscope and electron microprobe analyses on selected samples.

Based on field descriptions, the Upper Freeport coal bed of the phase one study area is divisible into eight facies: two nonbanded coal facies; four banded coal facies; and two shale partings. The thickness of the coal bed averages 211 cm (83 in.) in the northern part of the area where all eight facies are present; in the southern part, where only the four lower facies are present (three banded coal facies and one shale parting), the thickness averages 122 cm (48 in.).

Laboratory analyses showed that each of the six coal facies consists of distinct associations among macerals and the associated mineral matter. Areally, the facies showed trends which indicate that a specific set of conditions prevailed during the development of each facies in the ancestral peat-forming environment.

Areally, vitrinite reflectances correlated with prominent structural trends. Vertically within the bed, vitrinite reflectance was negatively correlated with low temperature ash and silica, indicating that increasing ash content retards coalification.

Microscopic analyses of pyrite and marcasite forms and their petrographic associations showed definite differences among the coal facies. Specifically, the bottom facies had framboidal pyrite, whereas the other facies contained more massive varieties of pyrite which should be more amenable to removal during coal preparation.

Accessory minerals found in the Upper Freeport coal using the scanning electron microscope, X-ray diffraction, and the electron microprobe probably contain most of the trace elements determined chemically.

Parametric and nonparametric statistics were applied to the analytical data of the phase one bench-channel samples (n = 75) to determine relationships among elements, forms of sulfur, mineral compositions of low temperature ashes, and maceral concentrations. The same statistical analyses were also conducted on samples with an ash content of 10 percent or less with potential energies of 12,660 kJ (12,000 Btu) or greater (n=46) and on all samples from the bottom four facies (n=37). The combined results indicate that the underlying statistical association is composed of two distinct groups of variables. Group I consists of elements, minerals, and macerals that correlate with ash, SiO_2, and Al_2O_3 content. Group II consists of elements, minerals, and macerals that correlate with sulfur.

Variation in mineral matter content of the Homer City, Pennsylvania, dedicated reserves of the Upper Freeport coal bed was primarily controlled by processes which were operable during the peat stage of coal formation. Those elements which make up Group I of the statistical correlations are believed to be derived predominantly from the inherent (plant) ash, whereas the variation of sulfur and related elements of Group II was primarily controlled by biochemical and chemical processes. A secondary control on sulfur variation is related to roof rock lithology; elevated sulfur contents occur under sandstone roof rock.

The present work is believed to represent a major contribution to the understanding of mineral matter variation in coal. In summary, it appears that mineral matter in coal is directly and indirectly controlled by the inherent plant ash and the pH and hydrologic conditions of the ancestral peat-forming environment. Low ash, low sulfur coal is the product of peat that formed under highly acid conditions (pH <4.5), whereas coal with higher ash and sulfur was formed under pH conditions that range from 4.5 to 7.5. Prediction of mineral matter variation in coal is best approached by a detailed geologic analysis of a given coal body from which paleoenvironmental parameters of plant communities, water chemistry, and hydrologic conditions can be delineated.

The work remaining for project completion consists of:

- Completion of a final report on phase one.
- Completion of data synthesis and a final report on phase two.
- Completion of laboratory analyses, data synthesis, and the preparation of a final report for phase three.
- All aspects of phase four including geologic field investigations, sample collection, laboratory analyses, data synthesis, and final report preparation.

Mineral Matter and Trace Elements in Coal

The Illinois State Geological Survey (ISGS) is also contributing to the EPA Coal Cleaning Program. The ISGS study aims to meet the need for increased information on mineral matter and on major, minor, and trace elements in coal which is necessary for optimal use of that fuel. The characterization of coal, with respect to mineral matter and chemical elements, will lead to an assessment of environmental hazards and economic potential involved in coal use and will aid in the design of preparation and cleaning processes for removal of contaminants.

The ISGS's three-year program on mineral matter and trace elements in coal has two major efforts:

- To characterize the No. 5 and No. 6 Illinois Basin coals by mapping the concentration of mineral matter and major, minor, and trace elements. Emphasis will be on those elements that are environmentally hazardous and/or of significance in synfuels production and conventional combustion. The maps can be used to predict concentration levels of the elements and mineral matter within the Illinois Basin for the No. 5 and No. 6 coals, and to select coal cleaning techniques for use with coals from different regions of the Illinois Basin.

- To establish organic and inorganic affinities of elements in Illinois Basin coals and locate, where possible, the inorganic sites of elements. Samples will be collected from different paleoenvironments, and the effect of differing paleoenvironments on the association of elements will be studied. Knowing the associations (organic and inorganic) of significant elements will aid in designing coal cleaning processes and in predicting the element's behavior during conventional combustion and conversion to synthetic fuels.

Under a separate EPA grant prior to FY 79, the Illinois State Geological Survey investigated the mineral matter distribution of the Illinois Herrin (No. 6) and Springfield-Harrisburg (No. 5) coals and the trace element occurrence and distribution in these coals. Rao and Gluskoter (1973)[6] related the distribution of individual minerals in the No. 6 coal to the paleogeography at the time of the No. 6 coal peat swamp. Ward (1977)[7], conducted a similar study of the mineral matter in the No. 5 coal. Gluskoter et al. (1977)[8] studied the occurrence and distribution of major, minor, and trace elements in the U.S. coals including 25 samples of the Illinois No. 5 coal and 53 samples of the Illinois No. 6 coal. This work examined the concentrations, enrichment factors, distributions, and organic and inorganic affinities of the elements in the coals.

FY 79 project work involved broadening the data base for the Illinois No. 5 and No. 6 coals by acquiring additional samples principally from areas not covered by the previous work (the central and eastern portions of the Illinois Basin). In the final year (FY 81) of this three-year project, the mineral matter and elemental data will be correlated with each other and with paleoenvironmental factors. The project will establish an elemental and mineralogical interpretation of the Illinois No. 5 and No. 6 coals, which can be used to locate coal with environmentally hazardous or economically recoverable elements. The interpretations can be used for selecting and developing coal cleaning techniques.

In all, approximately 40 samples of Illinois Springfield-Harrisburg (No. 5) and Herrin (No. 6) coals, primarily from the interior and eastern portions of the Basin for which there is presently a deficiency in data, will be chemically and mineralogically analyzed for elements of environmental and technological importance. Methods of analysis include: neutron activation, optical emission spectroscopy, atomic absorption, X-ray fluorescence, ion-selective electrode, X-ray diffraction, and scanning electron microscopy.

The organic and inorganic affinities of elements in Illinois Basin coal will be determined by subjecting whole coal samples of Illinois No. 5 and No. 6 coals to a series of specific gravity (float-sink) separations. Each fraction will be analyzed chemically and mineralogically by the techniques mentioned above. Two to three column samples will be collected from areas of differing paleoenvironments.

Twenty-one composite face channel and drill core samples (9 Illinois No. 5 coal and 12 Illinois No. 6 coal) have been collected this year for trace element and mineral matter analyses. Four of these samples were obtained with the stipulation of confidentiality of the data. In addition, three column samples have been collected for float-sink studies from which organic/inorganic elemental affinities are deduced. Two samples collected were high sulfur No. 5 and No. 6 coal from the same mine (from southern Illinois), and one sample was of low sulfur No. 6 coal from a different mine (from southern Illinois). All of the above samples, including each specific gravity fraction, are in the process of trace element analysis.

As part of the present program, trace element distribution data for the No. 6 coal from a previous study (Gluskoter et al., 1977)[8] are being mapped. Data obtained in FY 79 will be added to the mapping program as the analyses are completed. From the data available to date it is seen that approximately 15 elements have distinct distribution trends within the Illinois No. 6 coal. Six of these, the chalcophile elements Pb, Sb, Cu, Ni, Co, and As, show trends which can currently be related to a particular factor. The concentrations of these elements are high in the northwestern, eastern, and southeastern portions of the Illinois Basin and are believed to be related to areas of epigenetic mineralization and tectonic disturbances. The tri-state (Illinois, Iowa, Wisconsin) Pb-Zn mineralized district is located in northwestern Illinois. Evidence of some tectonic disturbance is present in this area in the form of numerous clay dikes in the coals. The Cave-in-Rock fluorite-galena-sphalerite mineralized area is located in southeastern Illinois. Conduits for the transmission of the ore-forming solutions are believed to be several fault systems in the area: Fluorospar Area Fault Complex, Wabash Valley Fault System, Cottage Grove Fault System, and Shawneetown Fault (Grogan and Bradbury, 1967).[9] The studies of Rao and Gluskoter (1973)[6] and Ward (1977)[7] related mineral distribution of the coals to the contemporaneous paleogeography of coal swamps, but from the above work it can be seen that the later history of a coal basin may be of significance in contributing to the inorganic constituents of the coal.

Non-clay mineral analysis has been completed for 15 of the 21 face channel and drill core samples and for all 27 of the float-sink separations. Major minerals present include pyrite, calcite, quartz, kaolinite, illite, and expandable clay minerals. Other minerals present in quantities identifiable by X-ray diffraction are chlorite, marcasite, sphalerite, and plagioclase feldspar. Maps of mineral composition trends for the No. 5 and No. 6 coals are being prepared.

Mineral analysis of the specific gravity fractions (Table 4-4) showed that even the lightest, most "mineral free" fraction in each set contained a residual amount of mineral matter. The minerals residual in the light

TABLE 4-4. MINERAL ANALYSIS OF LAW TEMPERATURE ASH: WASHED FRACTIONS

Analysis Number	Sample Type	% Recovery	LTA %	Pyrite *	Calcite *	Quartz *	Other Minerals *	Kaolinite	Illite	Chlorite	Marcasite	Sphalerite	Plagioclase	Gypsum	Anhydrite	Coquimbite	Other Sulfates
C20636	Raw	-	17.15	26	10	12	52	✓	✓	-	✓	-	✓	-	-	-	-
C20659	3/8 x 28M	-	13.89	24	8	16	52	✓	✓	-	✓	-	✓	-	-	-	✓
C20660	28M x 0	-	19.59	18	27	12	33	✓	✓	-	✓	-	✓	-	-	-	-
C20661	1.29F**	33.6	4.91	16	1	11	72	✓	✓	-	✓	-	✓	✓	-	-	-
C20662	1.20-1.31	19.8	7.18	16	2	13	69	✓	✓	-	✓	-	✓	✓	✓	-	-
C20663	1.31-1.33	10.3	9.64	16	2	15	67	✓	✓	-	✓	-	✓	✓	-	✓	-
C20664	1.33-1.40	19.1	13.96	11	2	16	71	✓	✓	-	✓	-	✓	✓	-	✓	-
C20665	1.40-1.60	10.5	24.66	9	4	17	70	✓	✓	-	✓	-	✓	-	-	-	✓
C20666	1.60S**	6.7	62.94	50	15	10	25	✓	✓	-	tr	-	-	-	-	-	-
C20637	Raw	-	13.00	29	4	14	53	✓	✓	-	✓	✓	-	-	-	✓	-
C20669	3/8 x 28M	-	12.43	22	4	12	62	✓	✓	-	✓	?	✓	-	✓	✓	-
C20670	28M x 0	-	15.36	34	8	12	46	✓	✓	-	✓	-	✓	-	-	✓	-
C20671	1.29F*	28.5	3.94	14	1	12	73	✓	✓	-	✓	-	✓	-	-	✓	-
C20672	1.29-1.31	19.9	6.49	12	1	15	72	✓	✓	-	✓	-	✓	-	-	✓	-
C20673	1.31-1.33	25.4	10.05	13	1	16	70	✓	✓	-	✓	-	✓	-	-	✓	-
C20674	1.33-1.40	12.7	15.25	18	1	16	65	✓	✓	✓	✓	-	✓	-	-	✓	-
C20675	1.40-1.60	9.3	25.34	29	2	18	51	✓	✓	✓	✓	-	✓	-	-	✓	-
C20676	1.60S**	4.2	57.15	62	13	5	20	✓	✓	-	✓	✓	✓	-	-	-	-
C20642	Raw	-	10.68	15	9	9	67	✓	✓	-	✓	-	✓	✓	-	-	-
C20683	3/8 x 28M	-	8.99	12	7	13	68	✓	✓	-	✓	-	✓	-	-	-	✓
C20684	28M x 0	-	17.29	15	25	6	54	✓	✓	-	✓	-	✓	-	-	-	-
C20685	1.28F*	43.7	3.15	20	2	8	70	✓	✓	-	✓	-	✓	-	-	-	-
C20686	1.29-1.31	20.5	5.02	15	2	10	70	✓	✓	-	✓	-	✓	✓	-	-	-
C20687	1.31-1.33	11.6	7.61	9	2	10	79	✓	✓	✓	✓	-	✓	-	-	-	-
C20688	1.33-1.40	15.4	12.71	6	2	10	82	✓	✓	✓	tr	-	✓	-	-	-	-
C20689	1.40-1.60	5.2	23.42	5	2	13	80	✓	✓	✓	tr	✓	✓	-	-	-	-
C20690	1.60S**	3.6	69.29	18	14	11	57	✓	✓	-	✓	-	✓	-	-	-	✓

* F = Float fraction
** S = Sink fraction
tr = Trace
? = Inconclusive Results

fractions are probably present as finely disseminated grains occluded within the pores of the coal particles and not readily separated by specific gravity methods. The minerals present in the 1.60 S* fraction are most probably those which were present as cleat (fracture) fillings and separate relatively easily from the coal. The small percentages of calcite in the light fractions, as opposed to the much larger percentage in the 1.60 S fraction, suggests that most of this mineral is present as cleat fillings rather than as finely disseminated particles.

Clay mineral analysis has been completed for 10 of the composite face channel and drill core samples. The percentages of kaolinite, illite, and expandable clays are very similar for all samples analyzed, regardless of whether they are from the No. 5 or No. 6 coal. Average percentages for these minerals follow:

Coal	% Kaolinite	% Illite	% Expandables
No. 5	29	37	34
No. 6	31	40	29

As more data become available, individual clay mineral percentages for both coals will be mapped and interpreted for trends.

Two fiscal years of this project remain. An additional 15-20 composite face channel and drill core samples will be collected from the Illinois No. 5 and No. 6 coals and analyzed for mineral composition and trace elements. At least three additional column samples will be collected, washed, and analyzed for organic and inorganic association of elements.

Both existing data from previous studies and data from the present study will be used in mapping the distribution of trace elements and minerals in the No. 5 and No. 6 coals of the Illinois Basin. Distributions of the above will be interpreted with regard to the paleoenvironment and paleogeography at the time of peat deposition and with regard to the post-Pennsylvanian geologic history of the Illinois Basin.

* Sink

Coal Environmental Profile System

Research Triangle Institute is also performing an environmental assessment study within the EPA Coal Cleaning Program. The Coal Environmental Profile System (CEPS) is a project activity under development to provide an environmental characterization of U.S. coals. In particular, coal transport/handling/storage systems, coal cleaning processes, and coal combustion processes are to be studied relative to their environmental interactions through:

- Fundamental laboratory tests and measurements.
- Use of currently existing data and programs.
- Projection of basic data to estimate variables of environmental significance.

Data developed from laboratory tests are to be combined with existing data on various U.S. coals to form a data base. These data will be composed of chemical analysis results, bioassay and other health effects data, and environmental engineering measures. Then, applications models will be used to project the fundamental results into practical industrial parameters, e.g., criteria pollutant loadings in storage pile run-off or in the stack gas of a conventional coal-fired electrical power plant burning the specific coal in question.

The CEPS program, once fully implemented, could provide:

- Information for environmental problem resolution with specific coals then in use.
- Recommendations for successful plant design or control system design for the utilization of specific coals.
- Guidelines for the ranking of coals with respect to environmental and health effect factors.

Environmental engineering tests on coals and the various products, byproducts, and waste streams are to be specified, as appropriate, to achieve the goals of the CEPS program. Among these tests are included

the dusting potential of raw coal and cleaned coal, leachate potentials for coal and coal-derived solid wastes, and the emission potential from spontaneous devolatilization. Physical properties of particulate solids of interest include particle size, resistivity, and permeability.

This project includes literature survey activities, project definition and system structure development, laboratory tests to validate or demonstrate selected test procedures of major importance, and data processing structure development. Reports dealing with the CEPS definition and structure, selected laboratory tests, data base and models, as well as system implementation and utilization are to be prepared.

During 1979, a dust generator was designed to produce a coal dust aerosol from raw coal in order to evaluate and compare the potential dustiness of different coals. The dust generator consists of an airtight aluminum cabinet, 46 x 61 x 46 cm high (18 x 24 x 18 in.) inside of which is a rotating cylindrical cage of steel mesh. Coal was placed inside this cage and tumbled, producing a coal dust aerosol inside of the cabinet. Humidity within the cabinet was controlled by pumping dry air into the box. The coal dust aerosol may be sampled at one of two sampling ports. A vacuum filtration device was used to sample the aerosol. The aerosol could be sized by connecting a sizing device, such as a cascade impactor, to an outlet port.

Repeated runs in the dust generator were done for two coals, western Kentucky No. 9 and North Dakota Zap lignite, using vacuum filtration for sampling the aerosol. Good reproducibility was achieved for western Kentucky No. 9 coal. Eight runs of the Zap lignite showed greater variability, but significantly less dust was produced than with the western Kentucky No. 9. Sample means (aerosol dust concentration) for the western Kentucky No. 9 coal and the Zap lignite were 0.50 mg/ℓ (0.22 gr/ft^3) and 0.19 mg/ℓ (0.08 gr/ft^3), respectively, for the same size coal loads and sampling time.

A MRI 1502 cascade impactor was used to size the aerosol produced from six different coals. None of the particle size distributions were log-normal, but were skewed such that the majority of particles were of smaller diameters. Generally, particle size distribution broadened with rank with median particle

size increasing from 6.8 μm (2.7×10^{-4} in.) for the Zap lignite to 9.5 μm (3.7×10^{-4} in.) for the Upper Freeport bituminous coal. For all coals, 50 percent or more of the dust produced was sized below 9 μm (3.5×10^{-4} in.). Hence, coal dust presents a significant inhalation hazard. Size distributions of dust generated from six different coals are shown in Figure 4-2.

A laboratory-scale coal cleaning experiment was conducted to demonstrate the feasibility of small-scale washability studies employing specific gravity separations. Studies of this type are relevant in evaluating the degree of sulfur and ash removal that can be expected in large-scale coal cleaning plants and the various quality/quantity options that exist. In addition, trace element correlations and affinities may be determined for particular coal types.

The separations were achieved via the float-sink method using flask and funnel apparatus of 5 ℓ (1.3 gal) capacity made for this purpose. Organic solutions having specific gravities of 1.3, 1.4, 1.6, and 1.9 were used successively to separate each coal sample into five parts. The float and sink fractions from each solution were dried and weighed; the sink fraction was then subjected to the solution with the next highest specific gravity.

Six separate samples were tested in this manner. Western Kentucky No. 9 bituminous coal and Wyoming Smith/Roland sub-bituminous coal were chosen as representative eastern and western coals. Separate samples of 3/8 in. x 100 M 16 M x 0 and 100 M x 0 were prepared and tested for each coal. For each sample, the yields of each of the five float-sink fractions (1.3 F*, 1.3-1.4, 1.4-1.6, 1.6-1.9, and 1.9 S**) were determined and the fractions were retained for chemical analysis.

Coal combines with oxygen when exposed to air in what can be considered low-temperature combustion. Like high-temperature burning of coal, oxidation at low temperatures releases heat. Low-temperature burning is incomplete and generates a spectrum of organic compounds of the same general type as those arising from pyrolysis or devolatilization of coal. Self-heating is the cause of this devolatilization. The lower-rank western coals,

* Float fraction
** Sink fraction

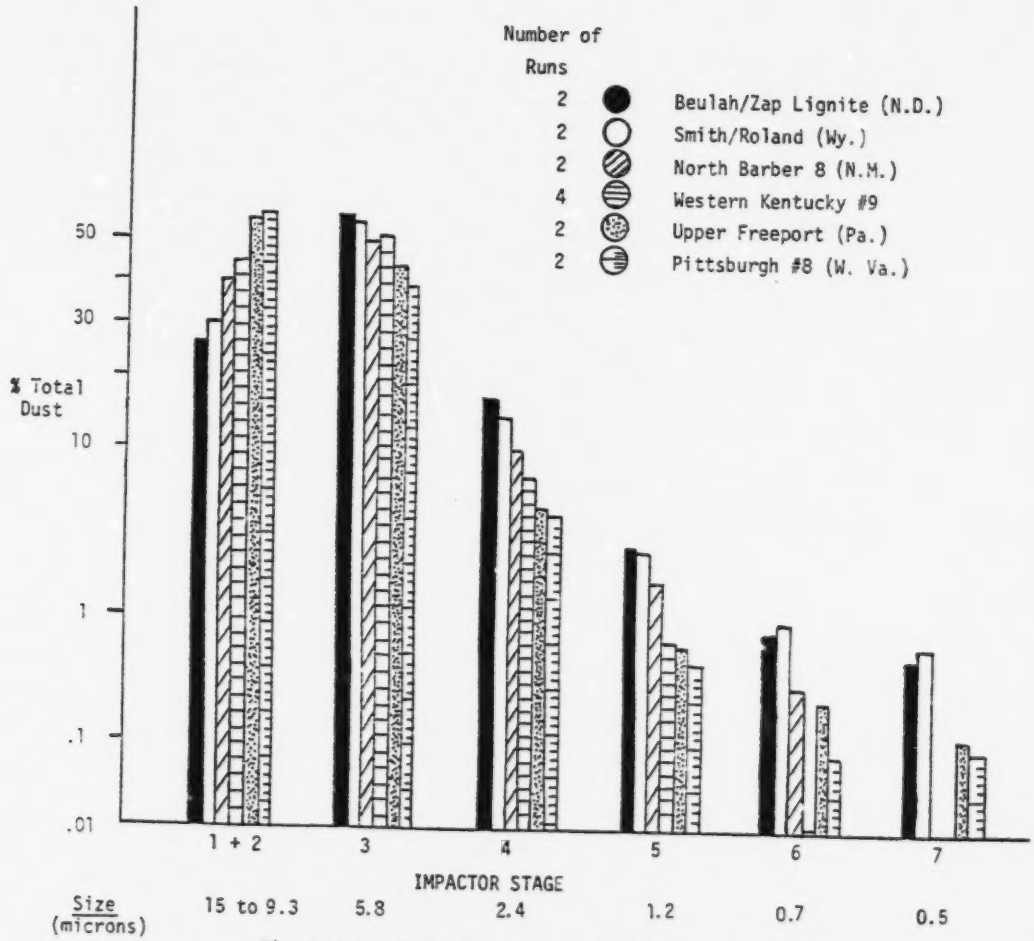

Figure 4-2. Coal dust particle size distributions.

which represent the largest U.S. reserves, are particularly prone to self-heating. The utilization of western reserves is increasing; a measure of self-heating would identify which coals require special attention. The technique of Differential Scanning Calorimetry (DSC) was used to measure the heat absorption or generation rate as the temperature of a coal sample was increased linearly. Either the rate of heat release at a given temperature and/or the amount of heat released when the sample is heated to a given temperature was used to rank the tendencies of different coals to self heat. A plot of heat release vs. temperature for three different fuels is shown in Figure 4-3. The quantification of thermogravimetric/DSC data permits a systematic approach to the evaluation of the devolatilization and self-ignition characteristics of various coals.

Planned activities include refinement of the devolatilization test procedure, and further analysis of data from the coal cleaning experiment. Additionally, in 1980, the design, construction and operation of a small-scale coal combustion unit is planned with the aim of producing representative fly ash samples for further testing.

Environmental Assessment Study

A major project was begun by Battelle Columbus Laboratories prior to 1979 and was continued by Versar Inc. and Teknekron Research, Inc. during FY 79. Battelle's efforts provided several automated data bases and two computer models which are being used in the ongoing effort by Versar and Teknekron. The investigation explores three major areas:

- Environmental impacts of coal cleaning processes.
- Coal availability.
- Environmental benefits of coal cleaning.

Each area contains multiple efforts, many of which are interrelated.

A major goal of the Environmental Assessment Program is establishment of a strong emissions data base for physical coal cleaning processes which will:

- Identify the coal cleaning processes that are most effective in minimizing pollution from coal use.

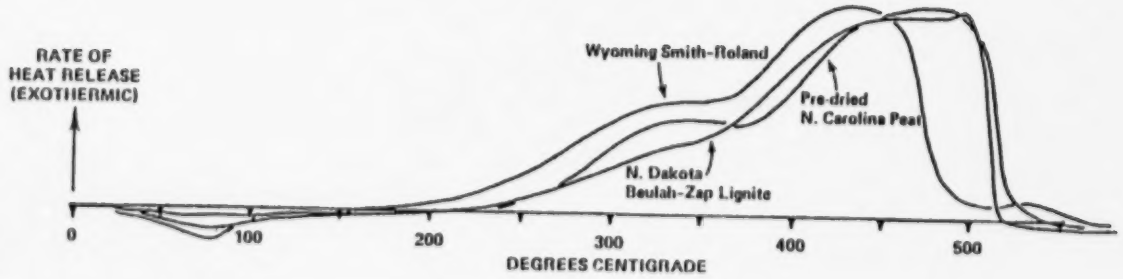

Figure 4-3. DSC results for carbonaceous fuels in air, 5°C/min.

- Characterize coal cleaning plants by obtaining and combining multimedia emissions data, relating them to plant operating conditions, and providing information on environmental effects of all effluent streams.
- Identify effective emission controls for coal preparation plants.
- Clarify and supplement results from previous environmental studies of coal cleaning facilities.

The sampling and analysis program includes physical, chemical, and biological testing of pollutant emission streams. It is being conducted on a multimedia basis, in accordance with an Industrial Environmental Research Laboratory phased approach that entails three levels of sampling and analysis. The initial effort (Level 1) tested all plant emissions to determine which effluent streams show the highest potential for measurably affecting health or the environment. This phase used generalized sampling and analytical techniques requiring an accuracy only to within a factor of three. Level 1 information provided preliminary environmental assessment data, identified problem areas, and allowed establishment of priorities for further testing of the various emission streams. Level 2 strategy is determined by the results of Level 1, and is designed to verify and expand those results. Level 3 includes long-term monitoring of an identified problem so that the variables affecting it are sufficiently quantified to provide a basis for control technology development. This phased approach offers benefits proportionate to the level of effort expended.

The Environmental Assessment Project will also use data gathered in prior media-specific EPA studies of coal cleaning plants, thereby expediting the Level 1 effort. Use of this baseline information allows the testing to incorporate some features of Level 2, and to provide a more precise measure of parameters. Plants tested at the start of this combined Level 1 and 2 phase will be investigated using Level 1 procedures to verify prior data and to ensure that no hazardous pollutants and streams are inadvertently omitted; plants tested later in this combined phase will be investigated with Level 2 procedures predominating. The results will define specific pollutant quantities being discharged (on a stream-by-stream basis) and will identify areas needing additional control technology development. Those discharges

requiring further definition or special consideration will be studied over long periods using continuous monitoring equipment as required by Level 3 protocol.

Actual field samples were taken at points upstream and downstream from the pollution control equipment and were measured primarily at the emissions source rather than in the ambient environment. Discharges already identified as having potentially adverse environmental effects are leachate and runoff from waste ponds and piles; fugitive dust from coal crushing and sizing areas, storage piles, and refuse piles; and thermal dryer emissions.

Results will be reported as a series of Source Test and Evaluation Reports (STER) culminating in an Environmental Assessment Report which will combine and interpret the previous STERs. This sequence will be followed for Levels 1, 2, and 3 assessments. Data from this effort will also be used for development of pollution control strategies and economic and environmental trade-off studies to determine optimal pollutant control.

Sites were selected with the purpose of obtaining a range of environmental conditions at various facilities. Four variables for site selection were considered:

- Neutralization potential of the soil.
- Pyritic sulfur content of the run-of-mine coal.
- Average annual rainfall.
- Complexity of the cleaning process being used.

During FY 79, physical and procedural preparations were completed for all testing and the first site was visited. Coding was completed for entry of the test data into EPA's Environmental Assessment Data System.

Environmental Regulations--

Because government regulations determine allowable pollutant emission rates and control technology, an overview of these requirements was conducted and data needs for future standards were gathered from government program offices. This information, along with our overview of coal cleaning pollution

control technologies, was compiled for submittal to EPA as Part I of an Environmental Research and Development Plan (ERDP) Report. State adoption of the 1979 New Source Performance Standards for Utility Boilers and revisions to State Implementation Plans are significant factors in the future of coal preparation; therefore, this information will be added to the ERDP in 1980.

Coal Data Base--

Another major focus of this coal cleaning project is the documentation of U.S. coal reserves relative to geography, potential heat-specific sulfur dioxide emission, cleanability, and heating value enhancement potential. The Resource Process Assessment Model (RPAM) developed by Battelle Columbus Laboratories is being used by Teknekron to project coal usage and availability by heat-specific sulfur content. During FY 79, model capabilities were extended, coal reserve data bases were correlated to determine geographical compatibility, and a production data base for the year 1976 was formed using annual reports submitted by coal companies to state agencies.

A planned production data base is being formed with information gathered from the U.S. Geological Survey, 1978 updates published by McGraw-Hill (Keystone 1979 Coal Mine Development and Expansion Survey), and the Ohio River Basin Energy Study compilation which estimates increased production in 1985 by county.

On a regional and state-by-state basis, lb $SO_2/10^6$ Btu histograms were developed for reserves, production, and deliveries data. RPAM was then run to generate raw coal availability at different emission standards when each of three physical coal cleaning processes were simulated. This was accomplished on both the production data base and the deliveries data base.

Preparation Plant Performance--

Another focus of the project is coal cleaning plant performance. The objective is to gather data on PCC process/cost modeling to be used in plant design and equipment determinations. Versar will maintain and extend the Coal Processing Simulation Model (CPSM4) developed by Battelle and will provide equipment cost and performance data from a previous Versar effort. Since coal cleaning plants are tailored for specific combinations of raw coal characteristics and product coal specifications, two approaches are being

taken. One is to develop computational tools, engineering design capability, and unit process parametric technical and economic data in a working format so that each coal cleaning plant design may be quantitatively tailored. The second approach is to produce case studies covering broad ranges of raw coals and product specifications, so that the performance vs. cost trade-offs can be quantified for various coal cleaning processes.

One problem being addressed in extension of the CPSM4 is the lack of washability data for a sufficient variety of feed coals and size and specific gravity functions. The largest source of washability data, RI 8118 (U.S. Bureau of Mines), does not contain the detail required for performance calculations for PCC plant design. Therefore, washability parameters must be correlated to each other such that minimum experimental data may be significantly extended through interpolation, without loss in precision or degree of confidence. The goals are (1) representation of washability data by a small number of parameters rather than by an extensive array of discrete values and (2) development of linear relationships between pairs of functions via careful definition of these functions.

A computer routine was developed to calculate functions and perform statistical analyses to determine the goodness of fit or linear correlations between pairs of functions. Table 4-5 lists the experimental, calculated, and interpolated values for the size distribution vs. weight-percent correlation. Calculations were also run for the ash percent vs. weight correlation, and for the sulfur percent vs. weight correlation. It can be observed that only a small decrease in precision results from interpolations. The implications are that these correlations provide a useful interpolation tool, permitting detailed performance calculations (with CPSM4) when only sparse washability data are available.

SO_2 Emission Control Alternatives--

A further objective of this coal project is to quantify the costs for compliance with a boiler emission standard, comparing coal cleaning with natural low sulfur coals and with boiler-specific sulfur dioxide control technologies such as flue gas desulfurization. This task would utilize the results of three prior tasks: coal resources data, cleaning process

TABLE 4-5. PRECISION OF SIZE DISTRIBUTION CORRELATION†
HOMER CITY FEED NO. 1

Size Fraction	Calculated Weight Percent			Direct Weight Percent		
	Experimental Value	Calculated* Value	Interpolated Value **	Experimental Value	Calculated* Value	Interpolated** Value
1 1/4 x 3/4	8.9	11.4	14.0	8.9	11.4	14.0
3/4 x 3/8	26.5	26.0	28.9	17.6	14.6	14.9
3/8 x 1/4	39.0	36.2	38.8	12.5	10.2	9.9
1/4 x 1/8	56.0	53.2	55.0	17.0	17.0	16.2
1/8 x 10M	65.2	66.1	67.2	9.2	13.0	12.2
10M x 28M	81.7	81.7	81.9	16.5	15.6	14.7
28M x 65M	90.3	90.6	90.5	8.6	8.9	8.6
65M x 100M	92.4	92.5	92.3	2.1	1.9	1.9

*Using all size fractions to generate correlation constant.

**Using 3 composite size fractions (1-1/4 x 1/4 in., 1/4 in. x 28 M, 28 M x 100 M) to generate correlation constants.

†Units in Table as reported to EPA. See Conversion/Identifier Table.

design and evaluation, and emission standards data. The results of this task will quantitatively define coal cleaning's potential in a clean fuels national strategy.

To determine fuel cycle costs, a Coal Cleaning Cost Performance Model is being developed which calculates the cost of coal cleaning by level (as defined by the user) and the associated cleaned coal characteristics (i.e., Btu/lb, sulfur, and ash content) at each level. The program is divided into several main components as follows: (1) raw and process data are entered (or default values may be used instead at the discretion of the user); (2) process curves are fit to the data by means of a "least-squares" regression; (3) levels of coal cleaning are defined by the user according to process type and fractional yields; (4) coal cleaning costs are computed, either on an annual or a levelized basis; and (5) a summary table of results (i.e., cleaned coal characteristics and associated costs) is developed.

NSPS for Industrial Boilers--

Technical studies were conducted in support of regulations being developed by The Office of Air Quality Planning and Standards (OAQPS). A short analysis of the supply/demand and characteristics of cleaned and uncleaned coal in the industrial boiler market was made to provide information on industrial boiler procurement practices. On the basis of this quick review, the following conclusions were reached:

- The industrial coal market is dominated by small coal firms that supply local industry and individually produce less than 181,450 kkg/y (200,000 tons/y).
- Except for the largest industrial coal users, industrial coal customers buy on the spot market or use short-term contracts. It is important to recognize that small industrial consumers are normally supplied by local coal.
- Typical industrial coal characteristics specifications are 1-3 percent sulfur, <10 percent ash, 27,910-30,240 J/g (12,000-13,000 Btu/lb) heating value, and a maximum of 10-20 percent fines (i.e., 1/4 in. x 0).

- Coal preparation plants are dedicated exclusively to the industrial market, except for a few captive plants.
- Only slight modifications in crushing and screening operations are needed to provide industrial fuel from a preparation plant producing utility steam coal.

Coal Sulfur Variability--

A second effort related to the development of air pollution regulations was the revision of a previous Versar report on Sulfur Variability of Clean Coals.

Sulfur content and heating value data for 53 different coal source-cleaning plant combinations were statistically analyzed to document the effectiveness of commercially operating coal cleaning plants in reducing sulfur and enhancing heating value and to define the effect of physical coal cleaning upon sulfur variability.[10]

The data included 33 data sets for unwashed coals, consisting of a total of 4,209 data points (lots), and 25 data sets for washed coals, consisting of 692 data points. Included in the "unwashed" category were run-of-mine (ROM) coals and coals cleaned to Level I (sizing to remove large rock). The "washed" category included Level II and higher coal preparation, where specific-gravity separation is conducted on one or more size fractions.

For each set of data points (lots), the mean ($\bar{Y}$), the standard deviation (Sy), and the relative standard deviation (RSD or $SY/\bar{Y}$) were calculated for total sulfur content, heating value, and heat-specific SO_2 content.

Matched pairs of feed and product data were available for eight sets of washed coals. For these data sets, analysis showed that both the absolute standard deviation and the relative standard deviation for all three coal characteristics were reduced by the coal preparation process. The reductions in both percent sulfur variability and lb $SO_2/10^6$ Btu variability were approximately 60 percent, while the heating value variability was reduced by approximately 80 percent.

Tests for autocorrelation of the data points within data sets gave positive results in 16 of 48 data sets (at the 95 percent confidence level). There is little doubt, therefore, that much of these coal data are serially correlated, verifying the expectations based upon geology and engineering rationale.

For each of 16 data sets which exhibited autocorrelation, the total variance (lb $SO_2/10^6$ Btu) was resolved into the long-term component, and associated with the serial correlation according to geostatistical concepts, and with the residual short-term (including sampling and analysis) component. An estimate of a generalized long-term component of relative standard deviation was 0.052, applicable to both unwashed coals and washed coals.

Estimates of the components of variability are:

	Uncleaned coals	Cleaned coals
RSD for long-term	0.052	0.052
RSD for short-term	0.096	0.053
RSD for S&A	0.045	0.023
(RSD) total for each source	0.118	0.078

It must be emphasized that these are generalized estimates, representing aggregated data sets. These values should not be used to characterize any one particular coal. Actual variabilities of individual data sets may be quite different from the generalized values shown above.

The total Environmental Assessment Project is scheduled for completion in 1983.

ASSESSMENT AND DEVELOPMENT OF COAL CLEANING TECHNIQUES

New pollution control standards and new directions in coal use, e.g., as a feedstock for synthetic fuels production, present increased challenges to coal cleaning technology. During FY 79, numerous coal cleaning projects focused on process development and assessment. Efforts were directed toward innovative coal cleaning techniques and economic evaluations of pollution control vs. cleaned coal alternatives.

Battelle Hydrothermal Process

The Battelle Hydrothermal Process treats a 70 percent minus 200 mesh coal with aqueous sodium and calcium hydroxides at elevated temperatures and pressures. This treatment has been found to remove nearly all pyritic sulfur and 25 to 50 percent of organic sulfur from Appalachian and eastern interior coals. Results from a previous study for the U.S. Environmental Protection Agency on Combustion of Hydrothermally Treated (HTT) Coals indicated that HTT coals are clean solid fuels which, in many instances, can be burned with little or no sulfur emissions. These fuels also have improved combustion properties.

During 1979, Battelle Columbus Laboratories continued work under this project with the following objectives in mind:

- To improve the economic viability of the hydrothermal coal process by reducing the cost of leachant regeneration and liquid/solid separation and to determine the potential of using this process for cleaning coal to comply with SO_2 emission regulations.

Efforts were made to achieve these objectives by:

- Evaluating methods for regenerating the spent leachant for recycle to the process.
- Evaluating the use of coarser coal on removal of spent leachant from the coal product.
- Assessing a number of methods for dewatering the coal product.
- Conducting process cost studies.

Through the use of coarser coals (-20 and -50 mesh as compared to -200 mesh) and other process modifications, significant process improvements in the liquid/solid separation segment were realized. Separation rates were increased by a factor of 10 by the addition of a dispersant in the amount of 0.25 kg/kkg (0.5 lb/ton) of coal processed. Sodium was effectively removed from the coal product with a reasonable number of washing stages by using saturated lime water as the washing medium. Wash water consumption was minimized by employing countercurrent slurry washing. Moisture content of the coal product was reduced from approximately 60 percent to approximately

40 percent by centrifugation, and the mineral matter content was reduced to below that of the raw coal during the desulfurization step and subsequent downstream processing. The final product from selected coals was a solid fuel with a reduced mineral matter content and acceptable sodium content, containing less than the equivalent of 520 ng SO_2/J (1.2 lb $SO_2/10^6$ Btu) and impregnated with a sulfur scavenger. Based on previous work, this coal product can probably be burned with little or no sulfur emissions.[11]

A number of materials were found to be effective in regeneration of the spent leachant for recycle by the removal of the sulfide sulfur. Of the systems evaluated, zinc oxide, ferrous and ferric hydroxides, reduced activated ferric oxide, and ferrous carbonate were effective in removing the major portion of the sulfide sulfur from the spent leachant.

Operating costs were estimated for a hypothetical self-contained hydrothermal treatment plant that processed coal at the rate of 363 kkg/h (400 tons/h) and employed the process improvements developed under this program. The operating costs include capital-related costs but not profit, interest, taxes, or fuel costs. For a typical eastern coal, e.g., a Pittsburgh seam coal, the cost was estimated to be $30.34/kkg ($27.52/ton); and for a western (subbituminous) coal, the cost was $6.89/kkg ($6.25/ton). For pricing considerations, profit, interest, and taxes were estimated at $11.11 and $4.27/kkg ($10.08 and $3.87/ton), respectively, for the eastern and western coals.

Some coals, i.e., those containing low concentrations of organic sulfur and high concentrations of pyritic sulfur, can be physically cleaned to produce a "deep cleaned" low sulfur coal product that will meet Federal New Source Performance Standards of 520 ng SO_2/J (1.2 lb $SO_2/10^6$ Btu) and a high sulfur coal product that will not meet new source standards. However, the high sulfur stream can be cleaned by hydrothermal treatment to meet new source standards.

Economic evaluation of a combined physical-hydrothermal treatment plant, producing 522 kkg/h (575 ton/h of cleaned coal [349 kkg (375 tons) by the hydrothermal process and 182 kkg/h (200 tons/h) by physical cleaning] indicated the operating costs to be approximately $18.85/kkg ($17.10/ton). This figure includes capital-related costs for the hydrothermal treatment, but not profit, interest, taxes, or cost of fuel.

The above costs do not include any credit for sulfur capture by the calcium in the HTT coal during combustion. Previous work for EPA indicated that approximately 50 to 100 percent of the sulfur remaining in the HTT coals was captured during the combustion of the calcium impregnated coals in a 0.5 kg/h (1 lb/h) and a 2.3 kg/h (50 lb/h) pulverized coal combustion unit. However, testing on a larger scale should be conducted to confirm sulfur capture in scale-up.[11] If the higher degree of sulfur capture is obtained in scale-up, the HTT coals could be a source of a solid fuel which would meet the new standards for sulfur emissions from coal combustion.

Homer City Coal Cleaning Plant

A project is being performed by Penelec at the advanced coal cleaning pilot plant that is under construction near the Homer City Generating Station Power Complex in Homer City, Pennsylvania. The facility is owned by Pennsylvania Electric Company (Penelec - a subsidiary of General Public Utilities Corporation) and New York State Electric and Gas Corporation. The project is jointly funded by EPA, DOE, Penelec, and the Electric Power Research Institute. The facility will process 4.7 Tg (5.2 million tons) of (ROM) coal per year, with a design capacity of 1.1 Gg/h (1,200 tons/h). The plant has four distinct process circuits: coarse coal, medium coal, fine coal, and fine coal scavenging. Unique design features of the Homer City plant include:

- Selective crushing to maximize the amount of 6 x 0.149 mm (1/4 in. x 100 M) coal.
- Use of small diameter [0.35 m (1.2 ft)] dense-medium cyclones to process the 2 x 0.149 mm (9 M x 100 M) size fractions.
- Computerized control of the magnetite slurry density.

The sole purpose of this plant is to clean coal for compliance with SO_2 emission standards for use by onsite units designed for both medium and low sulfur coals. The medium sulfur product will be used in two existing 600-MW generating units to meet the Pennsylvania SIP emission standard of 1.7 µg SO_2/J (4.0 lb $SO_2/10^6$ Btu). The low sulfur coal output will be used in a new 650-MW unit to meet Federal NSPS of 0.5 µg SO_2/J (1.2 lb $SO_2/10^6$ Btu).

EPA, Penelec, DOE, and the Electric Power Research Institute (EPRI) are providing cooperative support to a three-year test project at the Homer City complex with the following objectives:

- To determine the variability of sulfur and other pollutants in coal fed to the cleaning plant.
- To determine the performance of equipment used for separation of coal and pyrite.
- To determine the capability of plant process controls to maintain the coal product streams within specifications for sulfur, ash, and Btu content.
- To characterize pollutant streams emitted from the preparation and power plants.
- To determine the need for development of improved pollution control technology.
- To evaluate the effects of using cleaned coal on the performance of boilers and electrostatic precipitators at the power plant.
- To determine capital and operating costs of the preparation plants, i.e., the costs of using physical coal cleaning to meet SO_2 emission standards.

The preparation plant was constructed in two phases. The first phase, completed in October 1977, was capable of cleaning coal to meet an emission standard of 1.7 μg SO_2/J (4.0 lb $SO_2/10^6$ Btu), but was later phased out of normal operation by the addition of a low gravity cleaning circuit in the fall of 1978. Since the low gravity cleaning system was installed, complete with magnetite removal and coal crushing equipment, the plant has run sporadically with the goal of achieving steady-state operation at full load. Balanced operation between the cleaning and ancillary systems was not achieved at the plant during 1979. Operational upsets have been caused by excessive quantities of fine coal and misplaced magnetite built up in the clarified water system, an excess of fines in the incoming crushed coal, and an inadequate clarified water supply to slurry the coal in various subsystems.

Major equipment modifications have been scheduled for the first part of 1980.

Reports issued in 1979 measured the effectiveness of Electrostatic Precipitator (ESP) equipment while firing run-of-mine coal in the two types of precipitators which are used at the Homer City Power Station. The oldest precipitator tested performed acceptably, although marginally, while the newest and conservatively designed #3 unit performed outstandingly when run-of-mine coal was burned. An additional series of tests with ESP plate rapping suspended for various periods of time revealed that performance can be improved markedly by controlled plate rapping in sequence.

A separate report issued in 1979 provided plans for circuit tests to be done in the coal preparation plant when it is operating consistently. These tests of subsystems and individual equipment types in the preparation plant will characterize the effectiveness of each in removing sulfur and ash pollutants from coal. A related activity, which was completed in 1979, was that of developing a system to compile operating cost data from the preparation plant. When both performance and cost data are finally tied together by the test program, a gauge of sulfur removal cost effectiveness will be developed for the various types of cleaning equipment employed at the Homer City facility.

Another accomplishment during 1979 was the setting up and initial operation of a coal laboratory with specialized equipment for coal washability, ash analysis, and particle size distribution analyses to process large quantity samples. One ongoing phase of this task is the development of sufficiently tight quality control programs to regulate both the analytical and washability sampling requirements for the future test series.

Further goals of the Homer City program include:

- Completing the development of quality controlled coal sampling, flow monitoring, and coal analysis systems.
- Beginning equipment testing in the coal cleaning plant when operation in a steady-state condition is achieved.

- Completing the installation and check-out of an online sulfur and ash analyzer for the clean coal product stream.
- Sampling the cleaning plant input to assess the variability of coal from two onsite captive mines.
- Completing a report of boiler operation characteristics when using run-of-mine coal in Boiler #3 at Homer City. This is the first part of a task comparing cleaned coal and run-of-mine coal performance.
- Continuing data collection of coal preparation and power plant operating costs to compile an economic data base.

Dense-Medium Cyclone Project

The Department of Energy, in cooperation with EPA, EPRI, and the Homer City preparation plant owners, is conducting a comprehensive pilot-plant study of dense-medium cycloning of fine coal at lower-than-normal specific gravities of separation. Funds are being provided by DOE and Penelec. The objective of the project is to detail and optimize the performance of dense-medium cyclones on 9 M x 100 M coal at specific gravities around 1.30. A factorial test scheme is being employed to determine the effects of orifice sizes, inlet pressure, flow rate, medium-to-coal ratio, and magnetite size distribution on cyclone cleaning performance.

The project was initiated in May 1977. A dense-medium cyclone pilot plant was designed, fabricated, and constructed at DOE's Bruceton Laboratory, and shakedown tests were completed in June 1978. During this time the initial parameter levels were determined, and a test schedule was set up. Sufficient quantities of coal (Upper Freeport, 9 M x 100 M) and magnetite were obtained for the duration of the test program. Also, the testing and sample processing procedures at DOE were outlined, and the laboratory configuration, scope of work, and costs for sample analyses were determined.

The remainder of 1978 was spent assessing the impact of various parameters on the specific gravity of separation. To produce a 1.30 separation for each combination of variables, it was necessary to determine the medium density adjustments as a function of various test conditions.

In addition, tests were run without coal (using only magnetite and water) to measure the distribution of magnetite between the overflow and underflow (ΔS.G.) in an effort to develop a relationship between ΔS.G. and the differential (difference between medium density and the cutpoint).

During FY 79, magnetite/water testing continued along with a few spot tests using coal. The 71 medium-only tests and the first 33 coal tests helped to narrow the choices of orifice combinations, throughputs, and medium densities. On the basis of these tests, a new 60-test matrix was formulated. Two inlet orifices, 38 mm (1-1/2 in.) and 45 mm (1-3/4 in.), are being used, and each is being tested with an identical set of flow rates -- 5.8, 6.3, 6.9, 7.6, 8.8 ℓ/sec (92, 100, 110, 120, and 140 gal/min). These combinations define the effects of pressure versus throughput. Each of the above ten combinations is being run at medium-to-coal ratios of 3:1, 5:1, and 7:1. When necessary, tests are being run at two different medium densities to ensure a specific gravity of separation between 1.28 and 1.32.

About 30 matrix tests have been run to date. The factorial study will be completed shortly, and a report will be prepared. Testing will continue with emphasis on magnetite size distribution effects. This latter phase, involving about 25 tests, will conclude the cyclone test work; completion by the end of FY 80 is envisioned.

Initial data from the factorial testing were received in 1979; most tests were within the desired range of separation. All sample analyses should be completed by mid-1980.

In August, a study was initiated to compare various techniques of analyzing the size distribution of magnetite below 325 mesh. Representative samples of grades "E" and "B" magnetite were sent to various organizations for analysis on devices such as micro-sieve, Coulter Counter, HIAC, Sedigraph, Andreason pipette, Microtrac, and Image Analyzer. Based on factors such as cost, reproducibility, accuracy, simplicity, and measurement parameters, the devices and data will be evaluated for their applicability in magnetite size characterization. When all of the data have been received and analyzed, a report will be written.

The development of a viscometer for measuring the viscosity of a coal-magnetite-water slurry was also renewed. The viscometer designed by PEDCo and constructed by DOE is now at the Homer City analytical laboratory where efforts are underway to modify and calibrate the device to measure viscosities in the desired range with the necessary sensitivity. Other types of viscometers may also be tested.

Coal Cleaning Technology Assessment

During 1979 Versar Inc. performed a study to assess the applicability of using three pollution control technologies -- low sulfur coals, physical coal cleaning, and chemical coal cleaning -- for compliance with SO_2 emission regulations. The work was one of a series of studies in support of OAQPS to investigate the technological basis for a New Source Performance Standard for Industrial Boilers.

Candidate emission control systems were selected after initial consideration of six naturally occurring low sulfur coals, five levels of sulfur removal by PCC, and chemical desulfurization by eleven CCC processes. The Best System of Emission Reduction (BSER), defined as the technology which can comply with a given emission control level with the least economic, energy, and environmental impact, was identified for three coals at each of five emission control levels. Low sulfur western coal could meet all emission levels down to 516 ng SO_2/J (1.2 lb $SO_2/10^6$ Btu) without cleaning. The uncleaned low sulfur eastern coal achieved emission levels above 860 ng SO_2/J (2.0 lb $SO_2/10^6$ Btu). When physically cleaned, the low sulfur eastern coal could meet an emission level of 520 ng SO_2/J (1.2 lb $SO_2/10^6$ Btu). The candidate high sulfur coal could be cleaned to meet emission levels of 645 ng SO_2/J (1.5 lb $SO_2/10^6$ Btu) and higher. In the case of the high sulfur coal, chemical coal cleaning was needed to produce fuels capable of complying with an emission limit of 520 ng SO_2/J (1.2 lb $SO_2/10^6$ Btu).

It must be emphasized that the findings applied only to those coals evaluated. In general, each coal has a distinctly different desulfurization potential, and a rigorous analysis of coal cleaning as a pollution control technique must consider the coal to be used for each application.

To partially offset these facts, the study report also presented estimates of the amounts of U.S. coals which can be physically and chemically cleaned to various sulfur levels.

For regulatory purposes this assessment must be viewed as preliminary, pending the results of a more extensive examination of impacts by OAQPS called for under Section 111 of the Clean Air Act Amendments.

Another part of the Versar effort is a sampling and analysis task to evaluate the performance of three types of coal cleaning equipment -- heavy-media cyclones, hydrocyclones, and froth flotation units -- reducing pyritic sulfur content of fine coal. Sampling was performed at 10 coal preparation plants which use these types of equipment. The plants were chosen for the similarity of the feed size to their cleaning equipment and the comparability of the cleaning equipment, as well as for cooperation on the part of plant personnel.

Sampling was performed on five different days at each plant to determine the consistency of the data. Samples were taken of the feed, product, and refuse to the cleaning units, as well as of the overall plant products. All sampling and analyses except washability were performed on the plant site in the EPA Mobile Laboratory by Joy Manufacturing Company of Denver, Colorado. The analyses included ash, total sulfur, pyritic sulfur, and heat content. During FY 79, Joy submitted final test reports containing the results from these tests. From these results, the SO_2 emission reduction and the variance of the data can be determined.

The washability analyses on heavy-media cyclone circuits and hydrocyclone circuits were not completed. Those analyses which Joy completed were submitted to Versar as washability test reports, and more washability analyses are yet to be performed. Preliminary analysis of data submitted by Joy was begun by Versar during FY 79.

Evaluation of Physical and Chemical Coal Cleaning

The Tennessee Valley Authority in Muscle Shoals, Alabama, completed a study of seven coal cleaning processes to evaluate sulfur removal and economic viability of the processes when used alone and in combination with FGD.

The evaluation provides process descriptions, cleaning performances, comparative capital investments, and annual revenue requirements when four coals with sulfur levels of 0.7 percent, 2.0 percent, 3.5 percent, and 5.0 percent are cleaned by each of seven conceptual processes. In three commercial-type PCC processes, coal was treated in dense-medium equipment and by froth flotation or concentrating table. The three CCC processes are the KVB, TRW Gravichem, and Kennecott processes. The seventh process has PCC and CCC in combination. Economic information was also provided for three coal cleaning and FGD combinations to meet the pre-1978 520 ng SO_2/J (1.2 lb $SO_2/10^6$ Btu) NSPS and the 85 percent SO_2 reduction NSPS proposed in September 1978. All cases were sized for a 2,000 MW power plant.

The cleaning performance of the six coal cleaning processes are shown in Table 4-6 for the 5.0 percent sulfur coal. The PCC processes are limited to removal of pyritic sulfur and have a considerably lower sulfur removal efficiency than the CCC processes. In addition, there is a significant weight reduction from removal of non-coal minerals (as well as some coal) in the PCC processes. The CCC processes remove most of the pyritic sulfur and the KVB and Kennecott processes also remove 30 percent to 40 percent of the organic sulfur.

Sulfur removal efficiencies for the three PCC processes (designated as PCC I, PCC II, or PCC III) range from 30 percent to 36 percent on the basis of raw and cleaned coal heating values. Weight and Btu recoveries are about 84 percent and 91 percent, respectively. There is also an increase in cleaned coal heating value and a reduction in ash. Removal efficiencies of the CCC processes range from 63 percent to 75 percent with no appreciable weight or Btu loss. There is also less increase in heating value and less reduction in ash content compared with the PCC processes.

None of the coal cleaning processes can meet the 90 percent reduction New Source Performance Standards published in June 1979 within the range of coal sulfur contents evaluated. Each of the processes can meet the pre-1978 NSPS of 520 ng SO_2/J (1.2 lb $SO_2/10^6$ Btu), if the percentage of sulfur in the raw coal is below the limits shown in Table 4-7. Raw coal with a calorific value of 27,200 J/g (11,700 Btu/lb) will meet the 520 ng SO_2/J

TABLE 4-6. CLEANING PERFORMANCE OF PHYSICAL AND CHEMICAL COAL CLEANING PROCESSES *

5% SULFUR COAL

(MOISTURE-FREE BASIS)

		Clean coal						
		Physical cleaning			Chemical cleaning			Combination
	Raw coal	PCC I	PCC II	PCC III	KVB	TRW Gravichem	Kennecott	PCC I, KVB
Total sulfur, %	5.00	3.67	3.51	3.78	1.32	1.95	1.81	1.26
Pyritic sulfur, %	3.35	2.02	1.86	2.13	0.07	0.07	0.40	0.04
Organic sulfur, %	1.59	-	-	-	1.21	1.70	1.37	1.18
Sulfate sulfur, %	0.06	-	-	-	0.04	0.04	0.04	0.04
Ash, %	16.7	10.1	9.3	10.6	13.7	13.6	15.8	8.0
Btu/lb	12,000	13,000	13,000	12,900	12,900	12,300	11,300	13,600
Btu recovery, %	-	90.7	91.4	90.7	98.8	98.9	94.1	90.2
Weight recovery, %	-	84.2	84.0	84.7	92.1	92.8	100.1	80.1
Total sulfur, lb/MBtu	4.17	2.84	2.68	2.93	1.02	1.51	1.60	0.93
Sulfur removal, % Btu basis	-	32	36	30	76	64	62	78

TABLE 4-7. MAXIMUM SULFUR IN RAW COAL FOR MEETING THE 1.2 lb $SO_2/10^6$ BTU NSPS WITH COAL CLEANING*

(Moisture-free basis)

Coal-cleaning process	% sulfur limit in raw coal for meeting 1.2 lb SO_2/MBtu NSPS
No cleaning	0.8
PCC II, middling	1.0
PCC III	1.15
PCC I	1.2
PCC II, clean coal	1.7
Kennecott	2.1
TRW	2.1
KVB	3.1
PCC I-KVB	3.3

* Units in Tables as reported to EPA. See Conversion/Identifier Table .

(1.2 lb $SO_2/10^6$ Btu) NSPS at sulfur contents up to 0.74 percent. The PCC processes can produce coal meeting this NSPS from coals of 1.0 percent to 1.7 percent sulfur. The CCC processes meet this NSPS with coals containing 2.0 percent to 3.1 percent sulfur. The PCC I plus KVB combination process meets the 520 ng SO_2/J (1.2 lb $SO_2/10^6$ Btu) NSPS with coals containing up to 3.3 percent sulfur.

When SIP levels for existing power plants are higher than the 520 ng SO_2/J (1.2 lb $SO_2/10^6$ Btu) NSPS, the raw-coal sulfur tolerances increase noticeably. For example, at a SIP level of 1.7 μg SO_2/J (4 lb $SO_2/10^6$ Btu), PCC I can meet the SIP regulation with raw coal containing up to 3.9 percent sulfur.

For the PCC processes, the above results are at relatively high Btu recoveries (91 to 95 percent) and weight recoveries (84 to 91 percent). Under some circumstances, optimum conditions would call for somewhat lower recoveries to achieve slightly lower cleaned coal sulfur levels. This change is possible by conducting the gravity separations at specific gravities slightly lower than the 1.55 level used here.

Base-case capital investment and annual revenue requirements were developed. Summaries for the six processes are shown in Table 4-8. Costs of a limestone scrubbing FGD system with pond disposal of sludge are also included for comparison with the coal cleaning processes. All cost data are based on processes serving a 2,000 MW power plant and raw coal containing 5 percent sulfur, as described in the premises.

From the analyses, the following conclusions were reached:

- Physical coal cleaning is a commercial cost-effective method of meeting the pre-1978 520 ng SO_2/J (1.2 lb $SO_2/10^6$ Btu) NSPS for coals with sulfur levels below about 1.2 percent. Older utility plants that are required to meet less stringent State Implementation Plans or industrial boilers can utilize coals with higher sulfur levels.

TABLE 4-8. BASE-CASE PHYSICAL AND CHEMICAL COAL-CLEANING *

ECONOMIC DATA SUMMARY

Process	% Sulfur Reduction	Capital Investment		Annual Revenue Requirements	
		$/kW	¢/lb Sulfur Removed/Yr	Mills/kWh	¢/lb Sulfur Removed
PCC I	32	34	37	2.7	16
PCC II	36	40	40	2.9	16
PCC III	30	39	45	2.9	18
KVB	76	86	52	8.3	27
TRW	64	114	78	7.4	28
Kennecott	62	141	94	14.5	62
PCC I-KVB	78	115	59	11.0	32
FGD	85	119	68	5.6	18

Basis

2,000 MW, 5.0 percent sulfur in coal, 5,500 h/y, 9,500 Btu/kWh heat rate. FGD is limestone scrubbing, 25 percent scrubber redundancy, with pond sludge disposal. Percent sulfur reduction based on raw and cleaned coal heating values.

* Units in Table as reported to EPA. See Conversion/Identifier Table.

- Physical coal cleaning plus partial scrubbing with limestone FGD is generally cost effective in meeting the pre-1978 520 ng SO_2/J (1.2 lb $SO_2/10^6$ Btu) NSPS, as compared with FGD alone, for feed coals with sulfur contents below about 3 percent. Above this sulfur level physical coal cleaning plus FGD generally has lower capital investment but higher annual revenue requirements. When other benefits of using cleaned coal are credited, physical coal cleaning plus FGD should also be competitive at the higher sulfur levels.

- Coal cleaning plus partial scrubbing with limestone FGD is generally less cost effective in meeting the 85 percent SO_2 removal NSPS proposed in September 1978 than limestone FGD alone. KVB plus FGD and physical coal cleaning I plus FGD have about the same capital investment as FGD for sulfur levels

above about 3 percent but have higher annual revenue requirements. Again, credit for the other benefits of using cleaned coal can make physical coal cleaning I plus FGD competitive at the higher sulfur levels.

- The chemical coal cleaning processes studied are generally higher in both capital investments and annual revenue requirements than the physical coal cleaning processes. The Kennecott process is most expensive and the KVB process the least expensive of the chemical coal cleaning processes studied.

- The KVB process or KVB plus partial FGD scrubbing generally has lower capital investments and higher annual revenue requirements (mills/kWh) than FGD alone. Recent work by KVB to decrease the sodium hydroxide usage of this process could make a significant improvement in annual revenue requirements. All CCC processes require additional process development before costs can be accurately calculated.

- The KVB process is the most energy-efficient process of the physical coal cleaning and chemical coal cleaning processes studied.

- The use of cleaned coal has many additional economic benefits and a few penalties. The net result could be a cost reduction which would substantially reduce the costs of coal cleaning. Further work should be done to identify and quantify these factors.

- A potentially advantageous SO_2 emission control approach is pelletization of the already finely ground cleaned coal with limestone for further sulfur removal during combustion. This could expand the potential for economic sulfur removal by coal cleaning.

Physical Coal Cleaning Computer Economics

A second coal cleaning study being performed by TVA is the development of a computer program which will determine the most economical approach for sulfur removal using physical coal cleaning plus partial limestone scrubbing. The program will accept site-specific input variables such as coal composition, boiler size, transportation costs, cleaning process details, sulfur removal efficiencies, emission standard goals, and economic premises. No results are yet available, since the project was approved during the last week of FY 79 and scheduled for completion in early 1981.

Coal Cleaning Costs and Benefits

The possible advantages of using cleaned coals for utility boilers are a subject of key importance to the coal and utility industries. PEDCo has identified and quantified the benefits of using physically cleaned coal versus run-of-mine coal for utility steam electric generation. Available data from utility equipment manufacturers, government agencies, and published sources were used to identify coal-related boiler cost areas and to quantify the effects of improved coal quality on those boiler areas.

PEDCo's final project report has been prepared and submitted to the EPA Project Officer. The report identifies and quantifies several benefits associated with the use of physically cleaned coal in the operation of electric utility power plants. These benefits occur in three general areas: coal and ash handling, boiler operation, and gas handling and cleaning. The cleaning process removes sulfur from the coal and thus reduces the emissions of sulfur dioxide into the atmosphere. In many cases, however, the power plant must install supplemental control equipment to reduce emissions enough for compliance with environmental regulations. The cost of this supplemental equipment is less than the cost of a control system for use with uncleaned coal, but the cost increment is usually insufficient to offset coal cleaning costs. However, the combined total of all of the benefits addressed in this report generally exceeds the cost of cleaning the coal.

In a typical case, the cost of coal cleaning is $5.35/kkg ($4.85/ton) of cleaned coal, whereas the total benefits associated with the cleaning of the coal are estimated to be $7.94/kkg ($7.20/ton) of cleaned coal. PEDCo's final report recommends additional projects aimed at quantifying coal cleaning benefits, and presents an annotated bibliography of related studies.

Coal Desulfurization Using Microwave Energy

General Electric Company is continuing research into a process they developed prior to 1979 which removes pyritic and organic sulfur from several U.S. coals. The method utilizes microwave energy alone to remove 50 percent of the pyritic sulfur. In combination with sodium hydroxide it removes more than 95 percent of the pyritic sulfur and about 60 percent of the organic sulfur in exposure times of the order of one to three minutes at one atmosphere of inert gas. Additional sulfur is trapped in the ash when coal is burned accounting for almost complete absence of SO_2 in the combustion gases. The process temperature is a modest 250°C to 300°C, and the associated loss in the heating value of the treated coal is insignificant.

During 1979, further experiments have shown that microwave heating (in the absence of NaOH) converts pyrite (FeS_2) to strongly magnetic pyrrhotite which can, in turn, be removed magnetically very easily. Another significant result is that the atmosphere of the microwave treatment has an important effect on the nature of the conversion product. When treatment was performed in the presence of air, iron oxide was produced; in the presence of argon, pyrrhotite ($Fe_{1-x}S$) resulted.

The experimental correlation found between the microwave treatment atmosphere and the new phases produced suggests certain questions or conclusions. The "production" of pyrrhotite ($Fe_{1-x}S$) from pyrite (FeS_2) involves release of about one S atom per molecule of FeS_2, while the production of an iron oxide from the same pyrite suggests release of two S atoms. In other words, one might expect more sulfur reduction from samples treated in air than for those treated in argon, but not by a factor of two, because of other S bearing components. However, some data in this study indicate the opposite correlation, i.e., about 10 percent more S was removed in argon than in air. At the present writing, this conflict between ideas and results is not understood.

Another facet of the investigation relates to phase distribution after magnetic separation, relative to that in "as treated" samples. Inasmuch as the goal is desulfurization, the question is whether the non-magnetic pyrites follow along with the magnetic phase(s) in a magnetic separation. Early data suggest that the pyrrhotite formed is in very close association to the pyrites and is capable of carrying much of it along in a magnetic separation.

Although more analyses and data interpretation remain to be done, the potential for coal desulfurization by the microwave process appears to be very promising. The results of this study are extremely encouraging in terms of eventually reducing the coal desulfurization costs.

POLLUTION CONTROL TECHNOLOGY

Increased use of coal cleaning will result in additional needs for control of pollution from the cleaning process itself. Several EPA studies have focused on the area of possible environmental problems and potential solutions associated with coal cleaning emissions and waste streams.

Environmental Studies of Coal Cleaning Processes

The TVA is conducting a project for EPA that is comprised of two major tasks. The objectives of Task I are:

- To summarize available data on the characteristics of refuse and wastewater produced during coal cleaning.
- To characterize the waste streams from a level C (coarse beneficiation) coal cleaning plant.
- To assess coal cleaning's effect on the ash and wastewater characteristics of a coal-fired power plant.

The objectives of Task II are:

- To verify the characteristics of the waste streams from the level C coal cleaning plant in Task I.
- To characterize the leachate from the coarse and fine refuse disposal areas of a level C plant.

- To compare various leaching test procedures to that proposed under RCRA for measuring differences in leachate quality from the same refuse.

Prior to FY 79, available data on the characteristics of refuse and wastewater produced during coal cleaning were summarized and a waste characterization study was conducted at a level C coal cleaning plant (plant A). A draft report on Task I was submitted to EPA in September 1978. This report contained the summary of data on the characteristics of refuse and wastewater produced during coal cleaning and the raw data generated by the waste characterization study at plant A. The report did not contain an interpretation or discussion of the data generated by the waste characterization study.

During FY 79, the Task I report was revised to include EPA's comments, an interpretation of the data generated by the waste characterization study at plant A, and an assessment of coal cleaning's effect on the ash and wastewater characteristics of a coal-fired power plant.

Coal cleaning plant A has a design inflow coal capacity (Kentucky Nos. 9 and 11) of 816 kkg/h (900 tons/h). If operated as designed, the clean coal yield should be 65 percent. The plant uses about 9,085 ℓ (2,400 gal) of water per minute and operates on a closed water cycle. The fine refuse is disposed in a series of three ponds. The first two ponds serve as settling ponds for removal of the fine refuse. The third pond (clean water pond) provides further settling and storage of all surface runoff from the mine and coal cleaning plant site. The effluent from this pond (third pond) becomes the process make-up water, thus creating a closed water cycle.

The waste characterization study at plant A consisted of collecting a single set of grab samples from various process streams and effluents. Solid samples consisted of the incoming coal to the plant, coarse refuse, and the various grades of washed and dewatered cleaned coal. Slurry samples consisted of the process water from the head tank, fine refuse to the slurry pond (blackwater), cleaned coal from the jig, recycle from the middlings removal system, and the discharge to the polisher cyclone sump. Each slurry sample was filtered through a 1.2 μm (4.7×10^{-5} in.) membrane filter

to create a solid and a water sample. Water samples were taken in triplicate from the clean water pond effluent (process make-up water).

There were essentially four products and two byproducts from plant A. The products were cleaned coal in the size ranges 2 in. x 0, 1 x 2 mm, 8 M x 28 M, and 28 M x 100 M. The byproducts were coarse refuse and fine refuse. The raw coal had a relatively high ash content (48.8 percent) when compared to the ash content of coals burned at TVA coal-fired power plants (about 8 to 20 percent). Coal cleaning plant A reduced the ash content in the cleaned coal products to between 6.8 and 26.2 percent. The ash content of the coarse refuse was 74.7 percent while that of the fine refuse was 64.0 percent. The total sulfur content of the raw coal was in the range of coals normally burned at TVA's power plants (0.6 to 4.5 percent). The total sulfur content of the cleaned coal products remained about the same as in the raw coal.

Cleaning of the coal increased its heat content on a dry weight basis from about 15,800 J/g (6,800 Btu/lb) to about 27,900 J/g (12,000 Btu/lb). The cleaned coal yield for plant A during the study was calculated to be 38 percent based on an energy audit using the Btu/lb (dry weight basis) values for the raw coal, clean coal products and refuse. Based on this yield, coal cleaning plant A produces 1.63 kg of refuse for every one kg of clean coal produced.

Trace element balances for plant A were calculated based on a 38 percent cleaned coal yield and the average of elements found in the cleaned coal products and refuse. Overall the element balances were good. Between 76 and 119 percent of the elemental concentration in the raw coal was accounted for either in the refuse or clean coal except for Cl (59 percent), Zn (154 percent), and Hg (174 percent). Coal cleaning plant A reduced the concentrations of Cl, Ca, Mg, Fe, Mn, Cu, Ni, Cd, Pb, Cr, Ba, Be, and As in the coal while it increased the concentration of Zn, Hg, Se, and B in the coal. However, mercury was the only element that appeared to be substantially concentrated in the clean coal. Since this observation is based on only one sample of feed coal and some element balances were questionable, additional studies are needed to evaluate this finding. The dissolved concentrations of Mn, Cu, Zn, Ba, and As in the fine refuse slurry were below the water

quality criteria for domestic water supply intakes proposed by EPA.[12] Furthermore, the dissolved concentrations of Cn, Ag, Cd, Pb, Sb, Tl, Be, and Hg in the fine refuse slurry were below the minimum detectable limit. The dissolved iron and suspended solids concentrations of the fine refuse slurry exceeded the effluent limitations established by EPA for discharges from coal preparation plants.[13] At the time of sampling, the third pond effluent probably had not yet been affected by the coal cleaning plant. This was evidenced by the fact that the concentrations of sulfate, chloride, and selenium in the process make-up water (third pond effluent) were significantly lower than those dissolved in the fine refuse slurry.

The process make-up water and the fine refuse slurry filtrate were analyzed for the priority pollutants listed by EPA.[14] All samples were below 20 µg/ℓ except for tetrachloroethylene which was detected in all samples of the process make-up water. The concentrations ranged from 0.8 to 3.0 µg/ℓ. Tetrachloroethylene was used as a cleaning solvent within the plant and this probably accounts for its occurrence in the process make-up water.

The primary benefits of the level C coal cleaning plant in this study were that it reduces the ash content and increases the Btu content of the coal delivered to a power plant. If the sulfur content of a coal remains at a certain level, an increase in heating value of that coal results in a decrease in sulfur relative to heat. Thus, an increase in heating value of an environmentally unacceptable coal could enable it to meet a performance standard expressed in ng SO_2/J (or lb $SO_2/10^6$ Btu). This cleaning process would also cause a reduction in quantity of trace elements introduced into and emitted from a power plant. Although Zn, Se, and B were shown to be concentrated in the cleaned coal at plant A, their total quantities introduced into a power plant would also be reduced because of the increased heating value of the cleaned coal. In the case of Hg, however, calculations indicate that the increase in heating value of cleaned coal was not sufficient to offset the coal's increased Hg concentration. (This conclusion is based on only one set of sampling data.)

The effect of coal cleaning on the characteristics of the ash produced when cleaned coal is burned is uncertain. The total quantity of trace metals remaining for disposal after the combustion of cleaned coal will be less than that from combustion of raw coal, because some ash and trace metals will have been removed from the cleaned coal. However, this study indicated that a higher concentration of some trace metals would be found in the ash from combustion of the cleaned coal. For example, at plant A the ash content of the coal was reduced from 48.8 percent to 15.2 percent. Calculations showed that, of the elements studied, only Mg and Ba were reduced by a proportional amount; therefore, the other elements would have been present in higher concentrations in the ash from burning cleaned coal as compared to the ash from burning raw coal. In a previous study, TVA analyzed ash pond effluent and found that Cl, Ca, Ni, Pb, Cr, Hg, As, and Se were likely to be leached from ash to pond waters.[15] A constant proportion of ash to water coupled with a higher concentration of trace metals in the ash could result in higher concentrations of those metals in pond effluent. The leaching characteristics of the ash produced by burning cleaned coal would need to be determined to confirm whether the ash pond effluent characteristics would change from those of the previous study.

A draft report on the Task II activities is scheduled for submittal to EPA in September 1980. The Task II activities will consist of three major tasks:

- Waste characterization.
- Evaluation of laboratory leaching tests.
- Field leachate sampling.

TVA intends to conduct these tasks at the same coal cleaning plant as in Task I.

The waste characterization study will be conducted simultaneously with Versar's waste characterization survey at plant A being done under their environmental assessment program (Section 4). The results of this survey will be compared to the results of the Task I survey. Additional representative samples of the coarse and fine refuse will be collected for bench-scale testing of leachate formation and characterization. Five leaching methods will be addressed: EPA proposed extraction method, two

American Society for Testing and Materials (ASTM) methods, acid and base leaching method, and column leaching method. These methods will include the following test parameters: pH--3, 5, and 9; redox potential-anoxic, oxic; liquid to solid ratio--6 percent and 25 percent; and contact time--24 hours, 48 hours, 30 days. The leachate from the coarse and fine refuse disposal sites at plant A will be collected in the field for comparison with the leachates generated in the laboratory. Section lysimeters will be used to collect the leachate samples.

Preservation of Reactor Test Unit and Desulfurization of Gob Pile Samples

The development by TRW of the Meyers Process for ferric sulfate leaching of pyritic sulfur from coal has been sponsored by EPA through construction and operation of a 7 kkg/d (8 tons/d) test plant, termed the Reactor Test Unit (RTU). Operation of the test plant in 1977 and 1978 showed that the unit could be run continuously in three-shift operation to reduce the sulfur content of the feed coal to meet the 520 ng SO_2/J (1.2 lb $SO_2/10^6$ Btu) standard for new stationary sources. Corrosion problems were encountered in the stainless steel main reactor which required modifications prior to any further testing. The present problem provided a complete corrosion assessment, specification of a new main reactor of titanium, specification of a tail-end elemental sulfur extraction unit, and maintenance of the RTU.

The corrosion assessment inspection showed that the reactor vessel, the reactor internals, and the slurry recirculation loop equipment were severely corroded. Because of this, it was recommended that the original stainless steel reactor be replaced with a new reactor made of titanium. In addition, specifications were developed for a tail-end elemental sulfur extraction unit (TEU) to perform the second sulfur extraction step of the Meyers Process. The overall TEU design could operate on a continuous basis with sufficient liquid storage capacity to allow for up to seven days of uninterrupted flow.

A modification of the Meyers Process, the Gravichem Technique, involves a preliminary float and sink operation in the ferric sulfate leach solution, followed by Meyers processing of the sink (high pyrite) fraction. This

modification was investigated at bench scale in FY 79. Experimental verification and applicability assessment of this new approach was performed on both refuse and eastern Interior Basin run-of-mine coal. TRW concluded that application of the Gravichem process to eastern and midwestern steam-coal resources would reduce sulfur oxide emissions in the United States by 45 to 58 percent.

The Gravifloat Process uses the Meyers iron sulfate-sulfuric acid leach solution as a homogeneous dense medium to gravity-separate fine coal at specific gravities of 1.2 to 1.35. Thus, a significant portion of the input coal, which floats in the leach solution and is almost pyrite-free, may bypass the reactor, elemental sulfur extraction, and dryer steps of the Meyers Process. Only the sink fraction, which has a high concentration of pyrite, is taken through the Meyers Process. The float product is simply washed free of iron sulfate and is ready for use. Beneficial engineering cost improvements are obtained using this gravity-separation effect.

Some studies were done on run-of-mine coal, slurry pond wastes, and gob piles. It was found that the Gravifloat portion of the Gravichem Process can recover depyrited, very low ash and low sulfur fuel from waste coal fines found in slurry ponds. In addition, the Gravifloat coal in oil or water slurry is a potentially excellent fuel for use in switching oil-fired boilers to coal. Future work with the RTU will be done under the direction of the U.S. Department of Energy, to whom the test unit was transferred in September 1979.

Trace Element Characterization and Removal/Recovery from Raw Coal and Coal Preparation Wastes

A project of the Los Alamos Scientific Laboratory that is supported by DOE aims to assess the problem of trace element contamination in coal waste drainages and to identify suitable control technologies. More specifically, the aims are to:

- Assess the nature and magnitude of trace elements in the effluents from coal preparation wastes.
- Identify the chemistry of the trace constituents of environmental concern.

- Identify and verify experimentally effective environmental strategies to control the release of hazardous constituents.
- Analyze the trade-offs associated with the different control technologies and recommend control measures or necessary research, development, and demonstration programs.

To understand why coals and coal preparation wastes release elements in the amounts they do, LASL has studied the levels of trace elements found in coal wastes and the quantities of elements leached from the wastes. This was done for a low sulfur Appalachian coal area, where mineral drainage is not highly visible, and for high sulfur Illinois Basin areas where mineral drainage has long been recognized as a severe problem. Both types of wastes are composed primarily of clay minerals, quartz, iron sulfides, and calcite. Low sulfur Appalachian wastes have less than one percent iron sulfide minerals (pyrite and marcasite) as compared to 20-30 percent iron sulfides from high sulfur Illinois wastes. Some 55 elements have been identified, and undoubtedly there are more. The most abundant of these, aluminum, iron, and silicon, form the major minerals of the systems. The trace constituents are probably present as minor minerals (indeed even as tiny micro particles), components of residual coal, or substituents in the major minerals. A number of elements that are generally considered to be environmentally sensitive are present in significant quantities (>30 μg/g) in the waste. These elements of concern include aluminum, arsenic, cobalt, copper, fluorine, iron, lead, manganese, nickel, and zinc.

LASL work on trace element contamination of coal waste drainages from Illinois Basin high sulfur wastes has been recorded in past reports.[16,17] In the past years, research has been done on a coal waste from the Appalachian Region to characterize solid waste and trace element leachate. This work has been broken down into the two aforementioned areas of investigation. The first area involved studies of the mineralogy and elemental composition of low sulfur coal refuse samples collected from the Appalachian area; the second area concerned the aqueous leaching behavior of the materials.

The elemental composition of the Appalachian refuse is a reflection of its mineral matrix. Aluminum and silicon are by far the most abundant elements present in the refuse. From an environmental viewpoint, this low sulfur Appalachian refuse was found to contain potentially troublesome quantities of Al, Cu, Fe, Mn, Ni, and Zn.

Static and dynamic leaching tests were conducted on the Appalachian refuse material. These studies were designed to simulate the weathering and leaching behavior of the refuse materials, and to yield data on those potentially troublesome trace elements that may be released into the environment. An analysis of the data from the leaching experiments was made using Multimedia Environmental Goals established by the U.S. EPA. An element whose concentration is greater than the tabulated minimum acute toxicity effluent value[14] is designated as one of environmental concern. Based on this criterion, LASL identified Al, Cu, Fe, Mn, Ni, and Zn as those elements of environmental concern in the leachates from the sample of Appalachian Region refuse that was studied.

The research to identify and verify experimentally effective environmental strategies and specific controls to mitigate the release of hazardous constituents is broken down into three categories. The first two involve laboratory investigations while the third is an evaluation of potential control methods.

The first laboratory investigation addressed various options for treating coal refuse materials either at the preparation plant or during disposal to reduce subsequent releases of harmful trace elements during waste dump weathering and leaching. Among the potential methods that LASL investigated this year are calcining and preleaching of the refuse prior to disposal and applying neutralizing agents, adsorbents, and sealants to the dump itself to prevent contaminated drainage.

One of the more promising control strategies under investigation in the program is the calcining of the refuse (high temperature heat treating of the refuse materials) to remove volatile acid-forming constituents and to chemically immobilize potentially toxic trace elements in the fused matrix of the refuse. In this research, LASL has studied the changes in

both the chemical and physical characteristics of the calcined refuse and the leachabilities of the trace elements that remain in the inert refuse mass. This research has revealed that refuse calcining is technically one of the more effective and permanent means of treating high sulfur coal wastes to eliminate essentially subsequent releases of contaminated acidic drainage from refuse disposal sites.

Refuse preleaching has been studied to explore the feasibility of pretreating high sulfur coal refuse materials with aqueous leaching agents prior to disposal to remove some or all of the environmentally active trace elements and acid-forming constituents. Among the leaching agents that LASL investigated for this purpose were water alone, mixtures of water and oxidizing agents such as ferric salts and hydrogen peroxide, and oxidizing acids such as nitric acid. Since only the strong oxidizing acids appear to hold promise for removing a substantial proportion of the contaminants of concern through preleaching of the refuse samples that LASL studied, this activity has been de-emphasized.

Several methods were considered for treatment of coal refuse during disposal to prevent the release of trace contaminants during subsequent waste dump weathering or leaching by surface or ground water. These include co-disposal of the refuse material with neutralizing agents or trace element adsorbents and the application of watertight sealants to all or parts of the waste dump mass. Especially promising among these techniques is the co-disposal of high sulfur refuse with lime or limestone to neutralize acid drainage in situ and retain aqueous contaminants within the refuse disposal site.

Research has shown that the co-disposal of attenuating agents or sorbents, other than lime or limestone, with acidic coal refuse materials also has good potential for reducing or abating trace element contamination of disposal site drainage. Many natural materials, such as certain types of clay and soils, and many industrial wastes, such as fly ash or alkaline sludges, have considerable capacity to attenuate contaminated refuse drainage, and they often are available in large and accessible quantities near refuse disposal sites. Some of the research effort during the year was

directed at assessing the effectiveness of various attenuating agents for reducing the trace element and acid compositions of coal refuse leachates.

Another area of control technology being addressed is sealing the refuse pile, dump, or burial site to prevent the intrusion of air or water. The concept of sealing has overtones in all aspects of coal waste (and other waste) disposal. Sealants can be used for existing refuse piles and dumps, as well as for near surface and underground burial of wastes.

A variety of sealant scenarios, with an emphasis on clays, soils, calcite, and various cementing agents (Portland and silicate cements and polymers) as sealing agents, are being considered. Laboratory experiments have begun to test some of these materials.

The second category of laboratory research activity addressed environmental controls to reduce or attenuate undesirable trace elements in the drainages from coal refuse dumps. Attention in this area was given to pollution abatement techniques that have proven effective for treating acid mine drainage. These techniques include alkaline neutralization, ion exchange, and reverse osmosis. LASL has also initiated studies on the effectiveness of using a variety of sorbents such as clays, soils, and solid coal combustion byproducts on high sulfur coal refuse leachates.

Alkaline neutralization was shown to be the most effective and least costly of the refuse drainage treatment options studied. Ion exchange and reverse osmosis both proved to be technically feasible methods for reducing the contaminants in refuse drainage to acceptable levels; however, the necessity of treating the solutions further for acidity sharply reduced the applicability of these methods. This, coupled with the known tendency of ion exchange and reverse osmosis to overload or plug when the contaminant or suspended solids contents are high, leads to the conclusion that these techniques might be most applicable as secondary treatment methods to clean up the effluents from some other primary control process.

The non-laboratory portion of these investigations involved a discussion of the results and major implications from the research conducted thus far on control technologies for trace element contamination of coal refuse drainage. Included in this effort is a consideration

of the relative costs,[19] effectiveness, treatment duration, possible RCRA classification, and permanency of the most promising control method being studied. Making a selection from among the various control options is by no means a straightforward matter. The applicability of any of the control strategies to the real world must be evaluated in terms of the pertinent trade-offs. For example, coal refuse calcining has excellent potential for preventing release of trace elements from coal refuse piles and it is a one-time treatment, but it is expensive. Alkaline neutralization, on the other hand, is low in cost, but all the effluent from a given dump will have to be treated. And when the acid regeneration capability of the high sulfur wastes is considered, the acid effluent from a given refuse pile might have to be treated for more than a hundred years. Taking several of the more important factors into consideration, LASL has generated a comparison of several of the control options in the form of the following matrix (Table 4-9).

TABLE 4-9. COMPARISON OF ENVIRONMENTAL CONTROL OPTIONS

Parameter	Calcining	Codisposal	Alkaline Neutralization
Cost	High	Moderate	Low
Effectivness	Good	Good	Good
Complexity	High	Moderate	Moderate
Treatment duration	Short	Short	Long
Permanency	Good	Uncertain	Poor

In summary, the laboratory studies that have examined in detail the sources of trace elements in coal waste drainages, and the mechanisms of their release and fate weathering and leaching have provided sufficient understanding of the problem to address key environmental control technology issues effectively. A substantial portion of LASL's future efforts will be directed at identifying the most promising control options, demonstrating more clearly their utility, and analyzing the balances between their advantages and disadvantages. To broaden the scope of work, LASL will also include further studies on high sulfur coal wastes from the Appalachian

Region. These studies will define the potential of trace elements in these wastes to lead to undesirable environmental impacts and will identify the control technologies appropriate to mitigation of these environmental concerns.

Oil Agglomeration for Effluent Control

Battelle Columbus Laboratories is investigating techniques to enhance the efficiency of oil agglomeration for recovery of coal from preparation plant wastes. A previous laboratory study completed by Battelle under an EPA contract (No. 68-02-2112) demonstrated that coal recoveries of 90 percent or greater can be realized by using oil agglomeration on coal cleaning wastes.[20] The coal was recovered at these high levels from fresh blackwater sediments generated during coal cleaning, from aged sediments accumulated in slurry ponds, and from weathered and partially dried excavated sediments. Chemical pretreatment is needed to enhance separation of pyrite from the coal during oil agglomeration. However, pretreatment techniques that proved effective on finely ground coal had not been tried on coal cleaning wastes.[20] Battelle's present program is designed to supply that information.

The objectives of the current program are:

- To explore pretreatment methods which will cause the pyrite particles in blackwater to become hydrophilic.
- To effect pretreatment and oil agglomeration in blackwater and measure pyrite rejection and coal recovery.
- To assess the performance of oil agglomeration as an alternative or adjunct to existing effluent control of coal cleaning plants.
- To make recommendations for further study.

The program is evaluating oil agglomeration for waste streams from four categories of coal cleaning plants. The plants vary in complexity and effluent treatment and parallel those selected for sampling in the EPA program on "Environmental Assessment of Coal Cleaning Processes" (Section 4). Samples are taken at locations before and after any existing

effluent controls in the coal cleaning circuit or where appropriate for measurement of the necessary parameters. Specific sampling points may have to be determined on site if adequate information is not available prior to the plant visit.

Evaluations will include two or three fine coal cleaning wastes from various parts of the country. Thus far, slurry samples from one Kentucky and one Illinois coal cleaning plant have been characterized for their solids content, settling characteristics, sieve size distribution, and concentrations of ash, sulfur, and coal. Surface pretreatment methods for pyrite are screened by using pyrites and cleaned coal collected at the same place and time as the slurry samples. The most effective pretreatment method determined by the screening test is then used to treat the blackwater sediments. When completed in 1980, these studies should suggest agents and conditions which give optimum pyrite rejection and maximum coal recovery from coal cleaning blackwater. If further sampling verifies these conclusions, an engineering analysis will be performed and preliminary cost figures will be developed.

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GLOSSARY

areal map: Geologic map showing the horizontal area or extent of rock units showing above the surface.

calcining (calcination): The process of heating a solid to a high temperature to cause the decomposition of hydrates and carbonates.

epigenetic mineralization: Usually in the sense "formed after", particularly for ore deposits formed later than the enclosing rocks; also for sedimentary structures formed subsequently to the deposition of the sediment.

facies: General appearance or nature of one part of a rocky body as contrasted with other parts.

framboid: A microscopic aggregate of pyrite grains, often occurring in spheroidal clusters.

Level C coal cleaning: (coarse beneficiation) uses size reduction usually by crushers or rotary breakers, and cleaning of the coarse coal fraction (above 3/8 in.) by jigs or heavy-media washing units. The primary benefit is ash removal.

lithology: The physical characteristic of a rock, generally determined megascopically or with the aid of a low-power magnifier.

macerals: The banded ingredients of coal such as vitrinite.

paleoenvironmental: The environmental aspects of past geologic ages.

paleogeography: The geography of an area at some stage in past geologic ages.

pyrolysis: The subjection of organic compounds to very high temperatures.

slagging properties: The physical and chemical characteristics of molten coal ash which is composed primarily of silica, alumina, iron oxides, and calcium and magnesium oxides.

tectonic disturbances: Broad structural disturbances in the earth's crust.

vitrinite: Thin horizontal bands in coal having brilliant gloss and mirror-like reflective properties.